



US009461051B2

(12) **United States Patent**
Park et al.

(10) **Patent No.:** **US 9,461,051 B2**
(45) **Date of Patent:** **Oct. 4, 2016**

(54) **METHODS OF FORMING ELECTRONIC DEVICES HAVING PADS USING FIRST AND SECOND MASKS**

(2013.01); *H01L 21/76897* (2013.01); *H01L 27/1085* (2013.01); *H01L 27/10885* (2013.01); *H01L 27/10894* (2013.01); *H01L 27/10897* (2013.01)

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Yoo-Sang Hwang, Suwon-si (KR);
Hyeon-Ok Jung, Daejeon (KR)

(58) **Field of Classification Search**

None

See application file for complete search history.

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Hyun-Chul Yoon, Seongnam-si (KR);
Yoo-Sang Hwang, Suwon-si (KR);
Hyeon-Ok Jung, Daejeon (KR)

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(73) Assignee: **Samsung Electronics Co., Ltd.** (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **14/847,324**

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(22) Filed: **Sep. 8, 2015**

(65) **Prior Publication Data**

US 2016/0027787 A1 Jan. 28, 2016

Related U.S. Application Data

(63) Continuation of application No. 14/105,581, filed on Dec. 13, 2013, now abandoned.

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(30) **Foreign Application Priority Data**

Jun. 20, 2013 (KR) 10-2013-0070688

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(74) *Attorney, Agent, or Firm* — Myers Bigel & Sibley, P.A.

(51) **Int. Cl.**

H01L 27/108 (2006.01)

H01L 21/3213 (2006.01)

H01L 21/768 (2006.01)

H01L 21/033 (2006.01)

H01L 21/311 (2006.01)

(57)

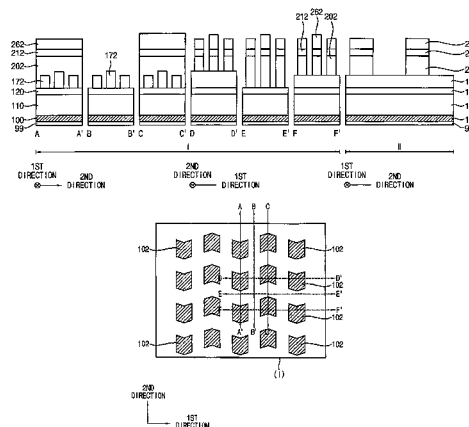
ABSTRACT

An electronic device may include a substrate, and a plurality of spaced apart pads on the substrate. Each of the pads may include first, second, third, and fourth sides, the first and third sides may be opposite sides that are substantially straight, and the second and fourth sides may be opposite sides that are curved. Related methods, devices, and structures are also discussed.

(52) **U.S. Cl.**

CPC *H01L 27/10855* (2013.01); *H01L 21/0337* (2013.01); *H01L 21/31144* (2013.01); *H01L 21/32139* (2013.01); *H01L 21/76895*

22 Claims, 51 Drawing Sheets



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FIG. 1

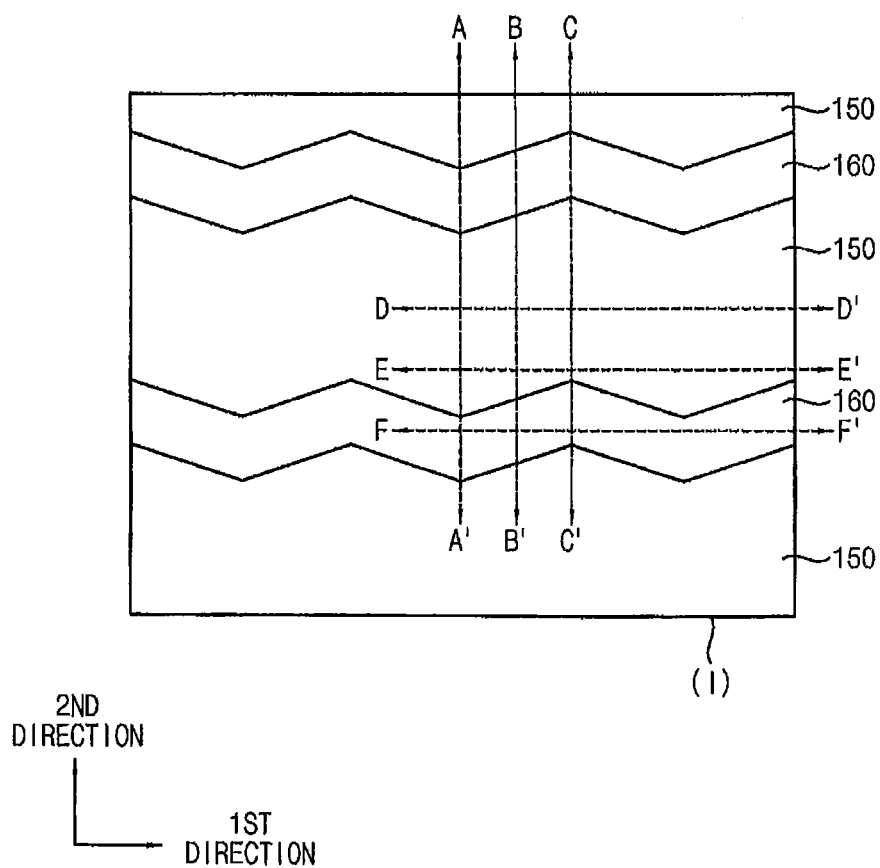


FIG. 2

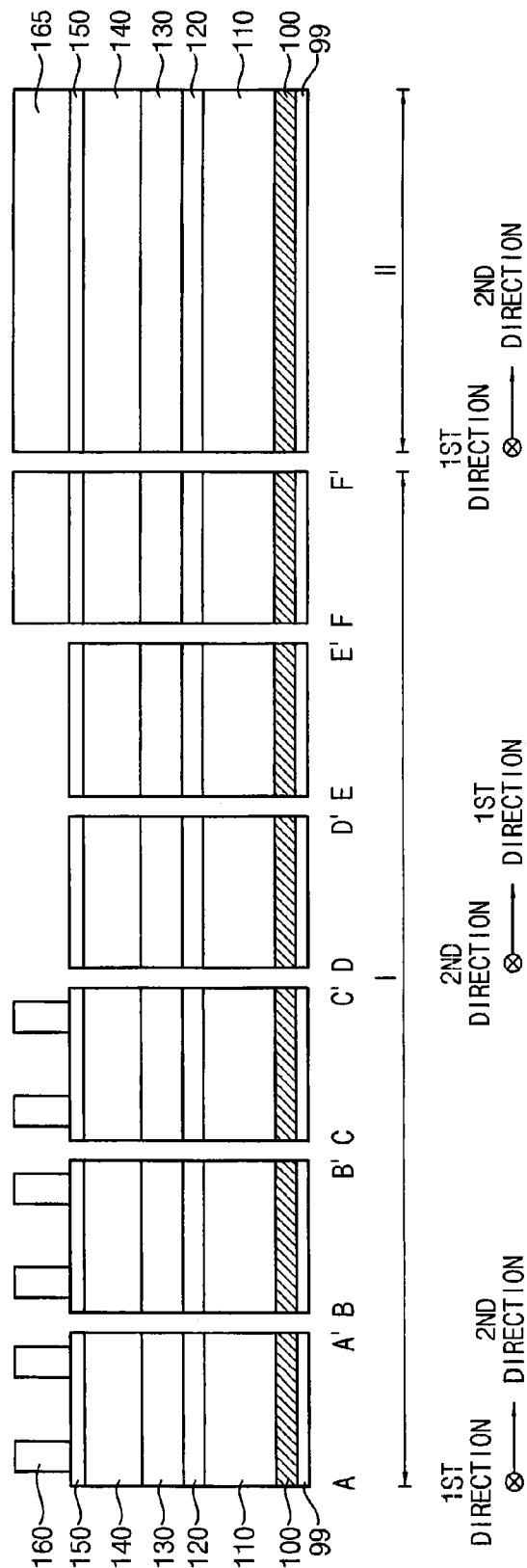


FIG. 3

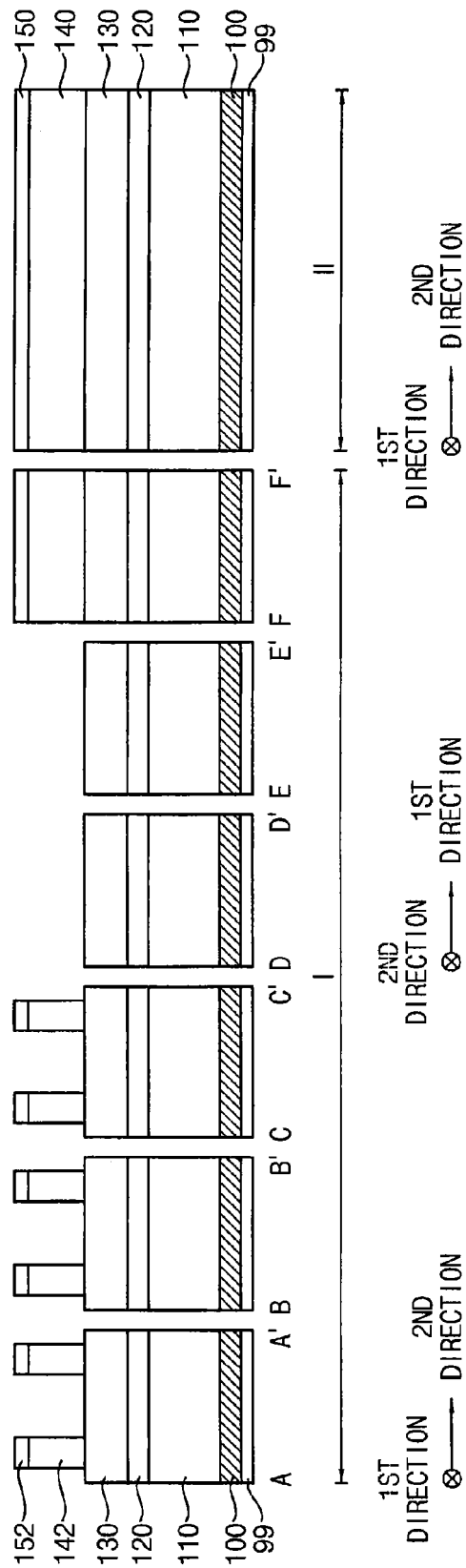


FIG. 4

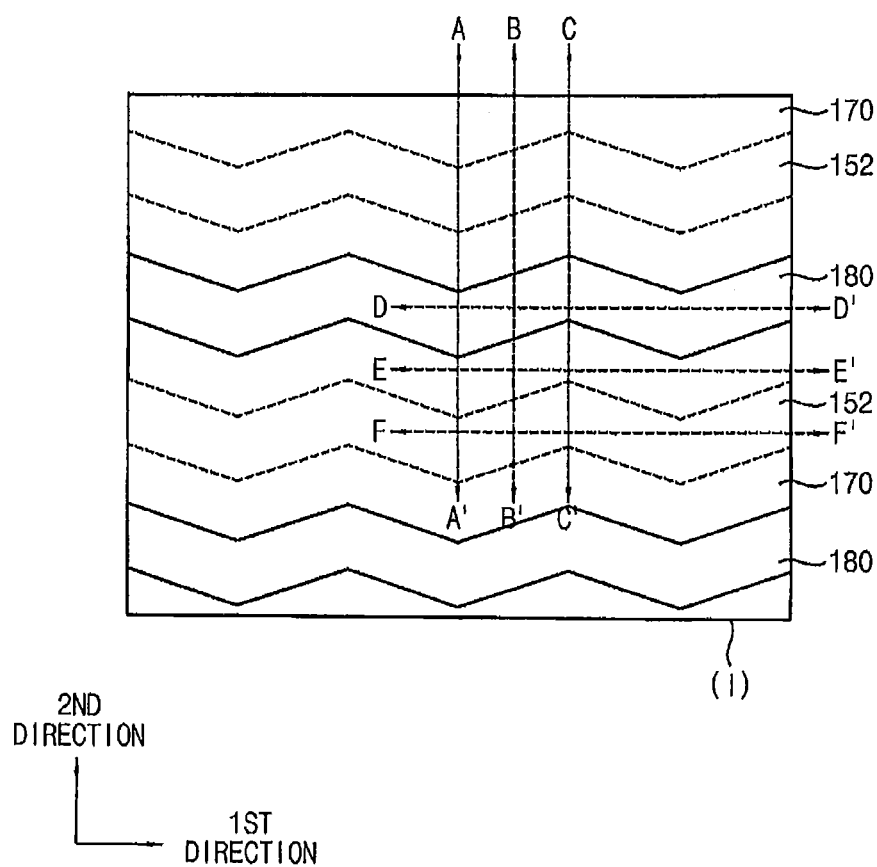


FIG. 5

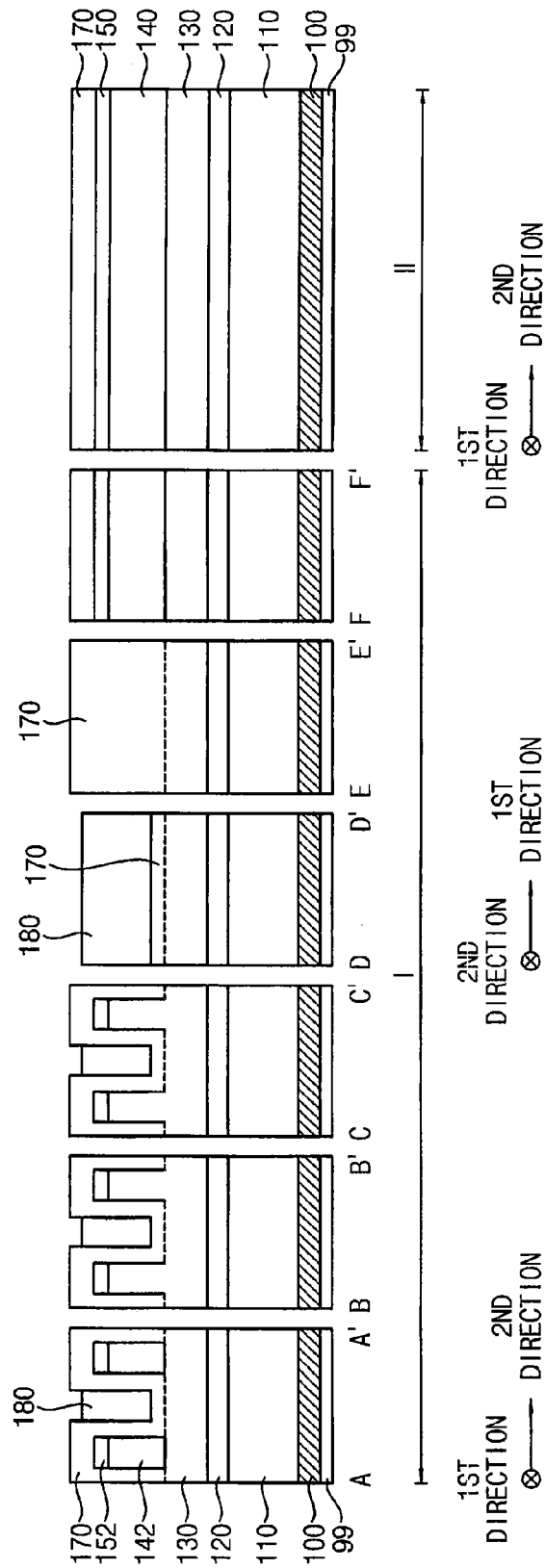


FIG. 6

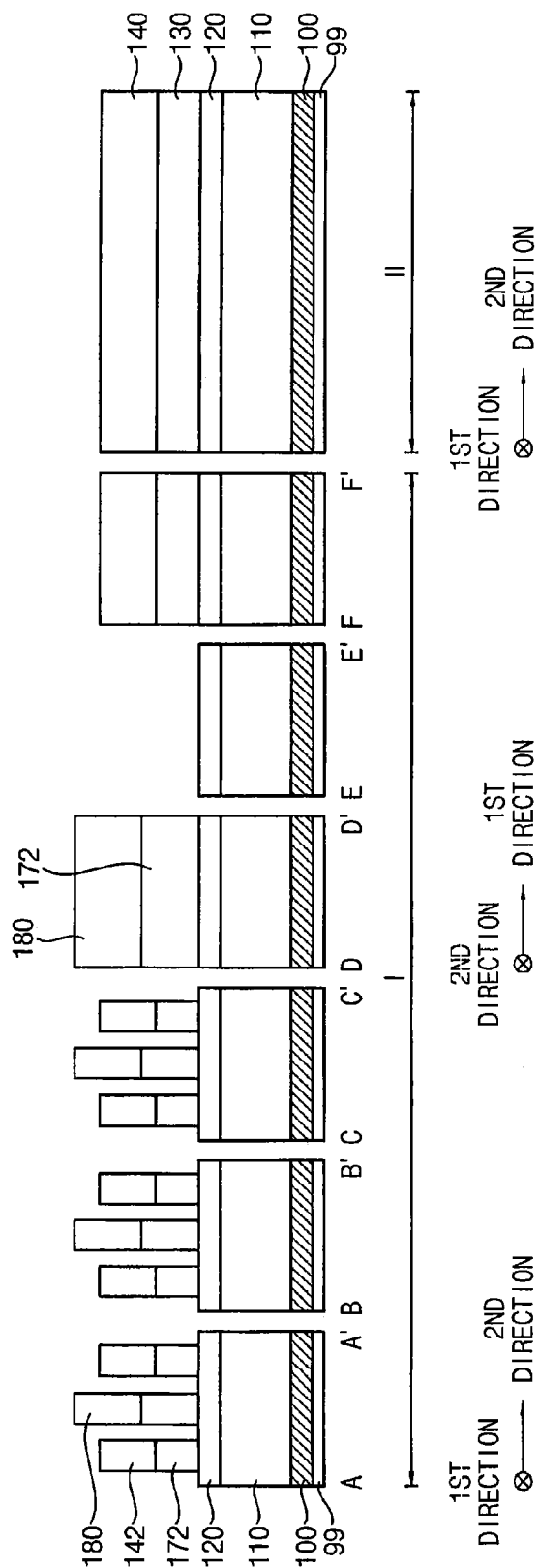


FIG. 7

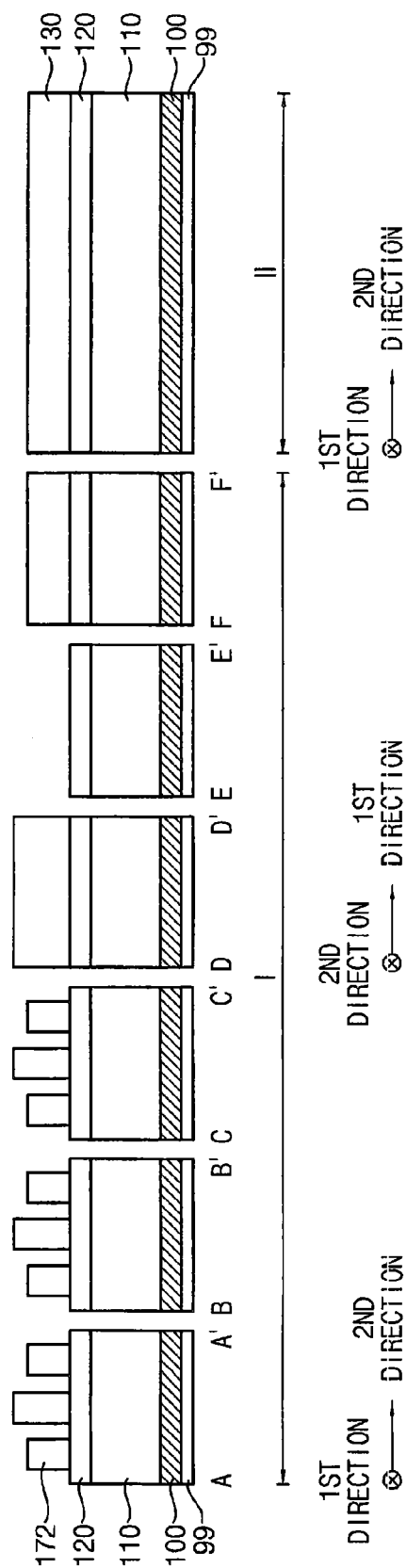


FIG. 8

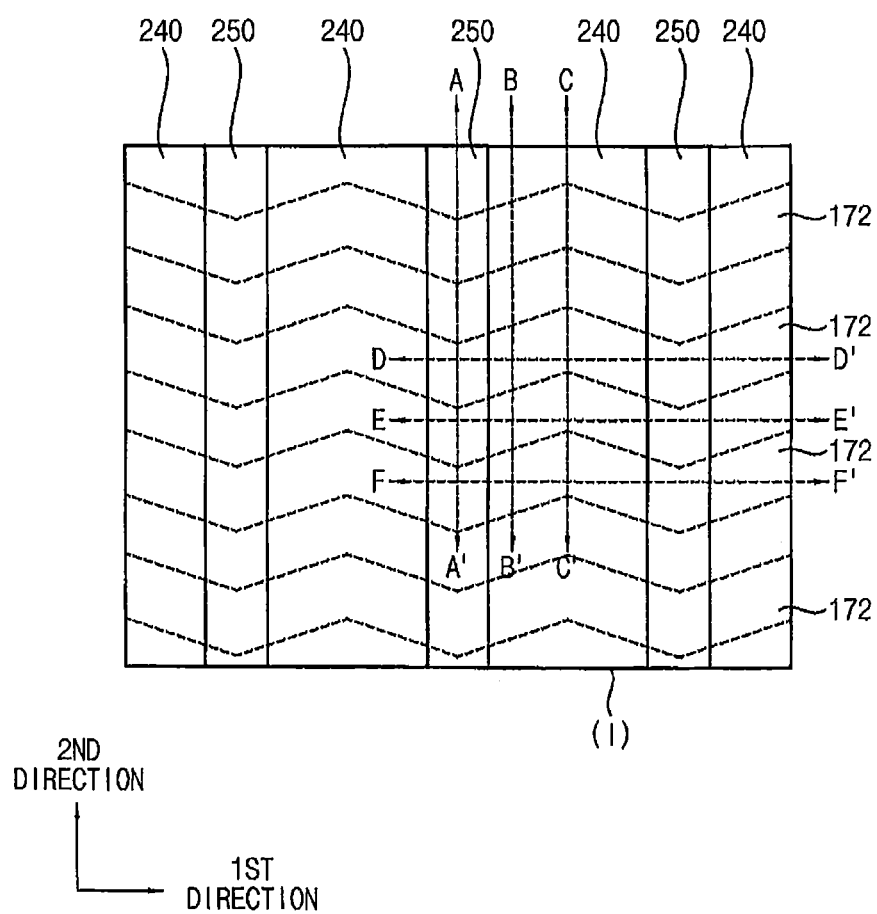


FIG. 9

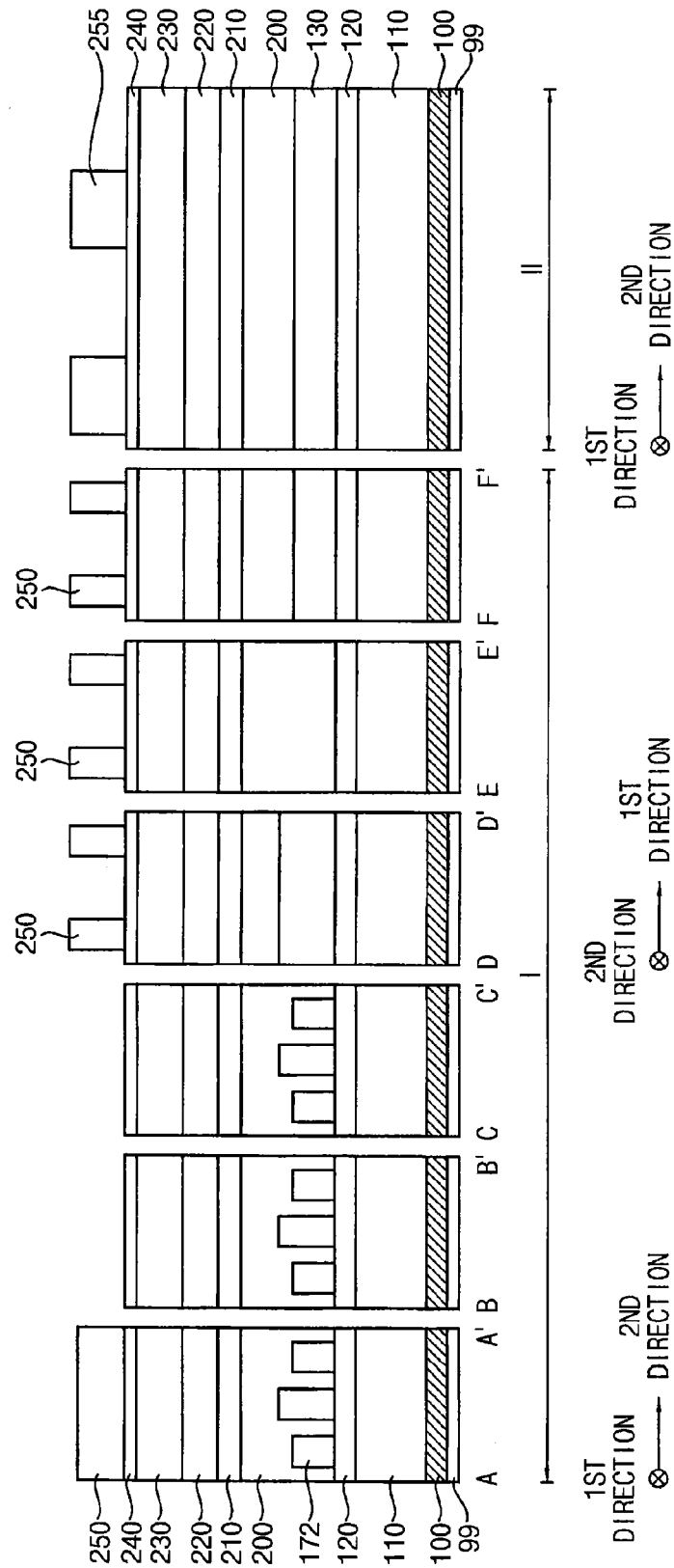


FIG. 10

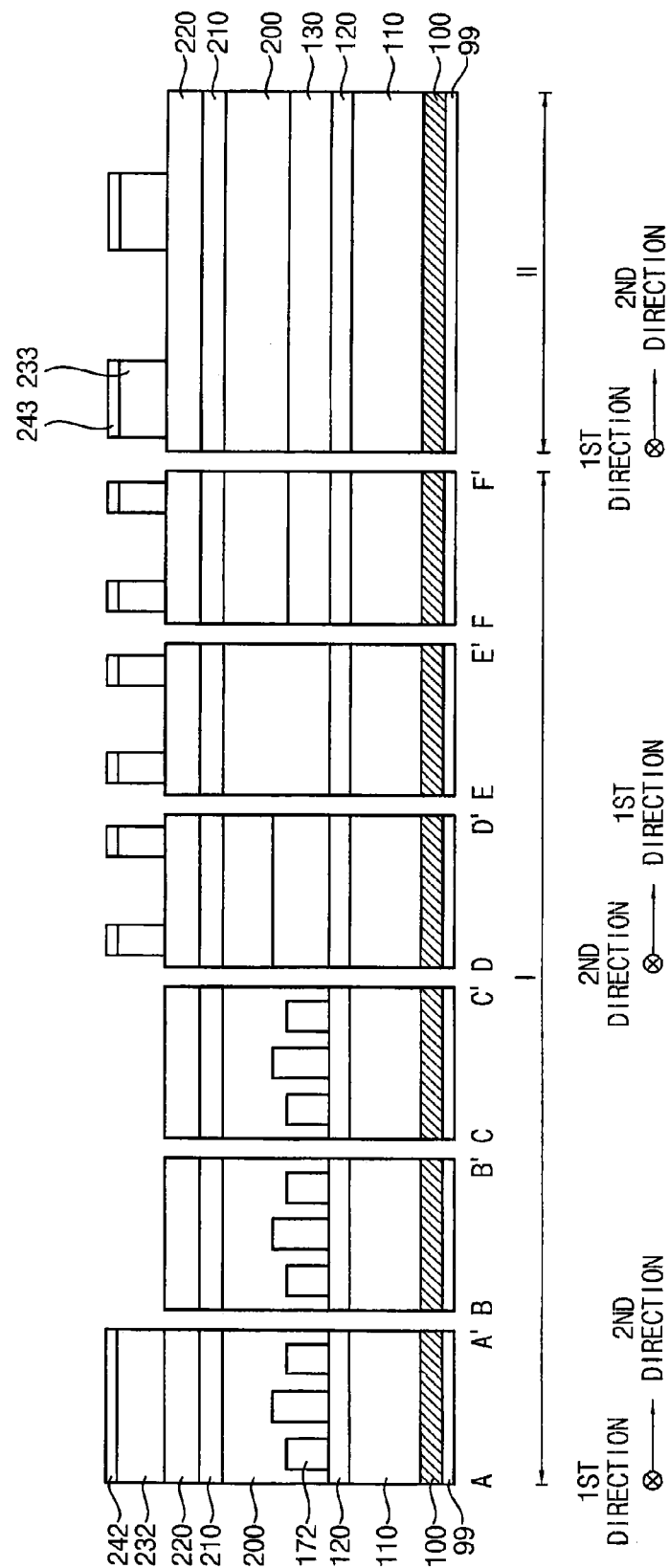


FIG. 11

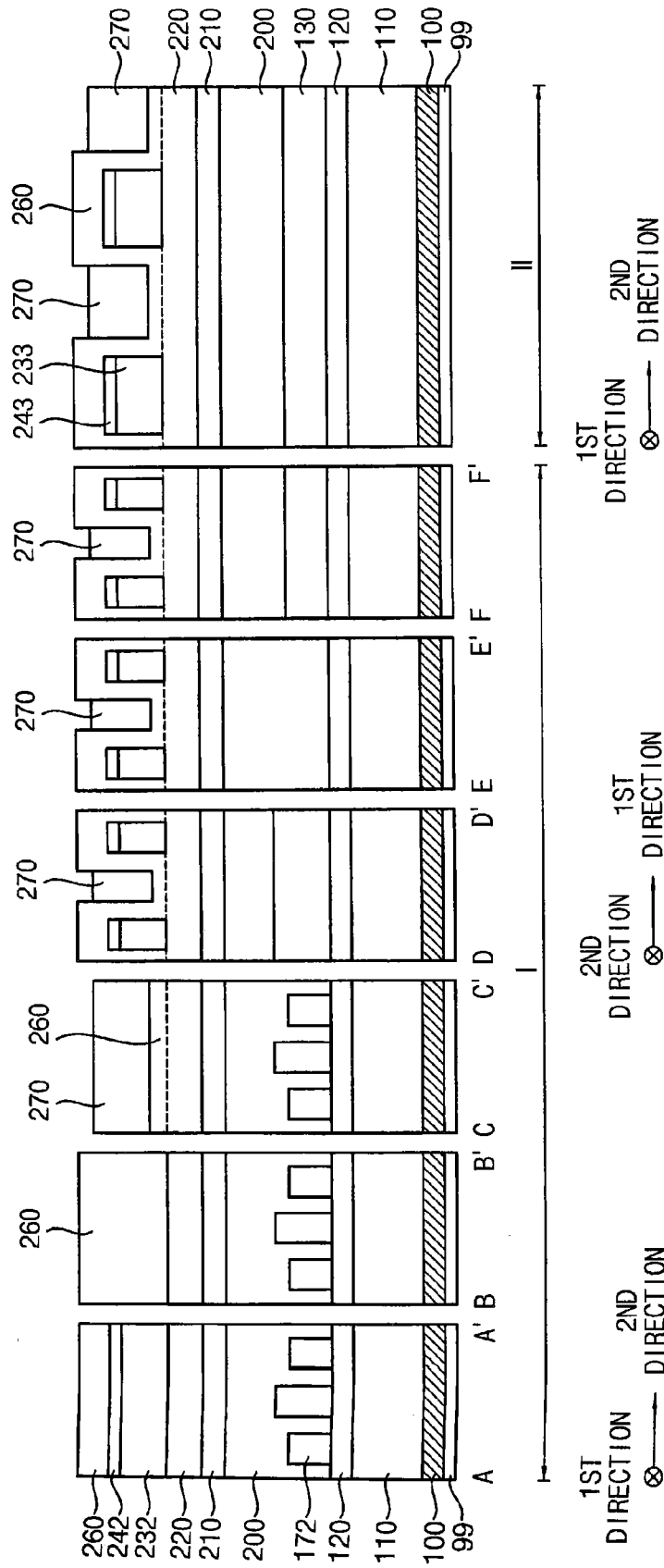


FIG. 13

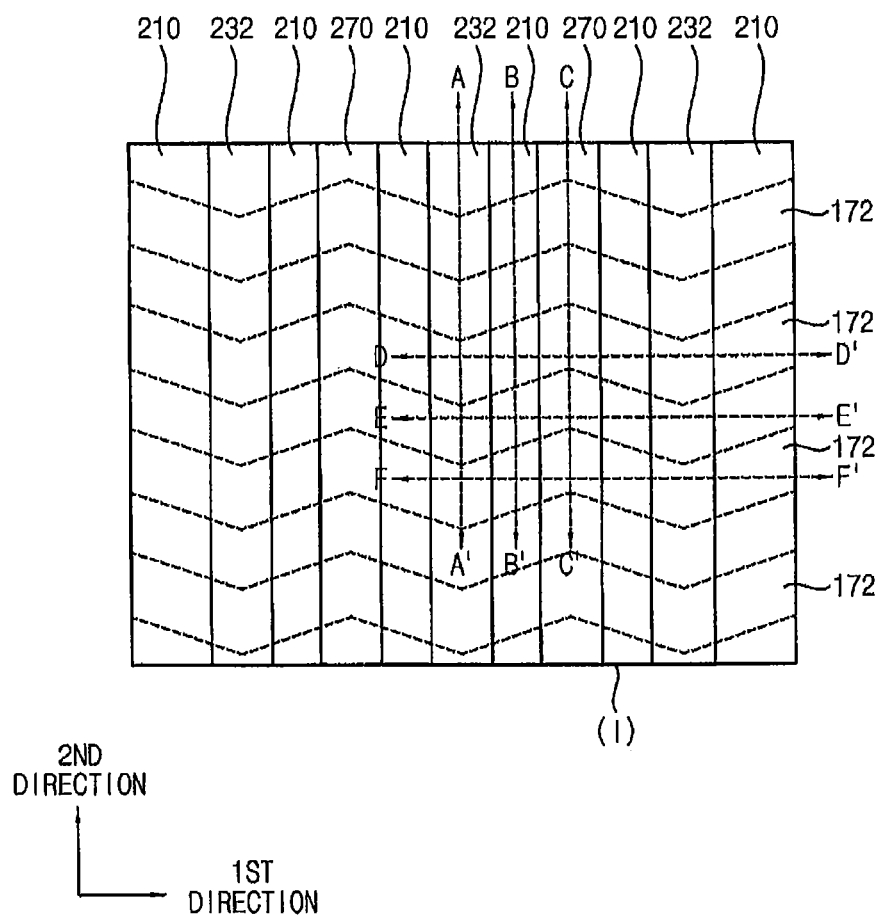


FIG. 14

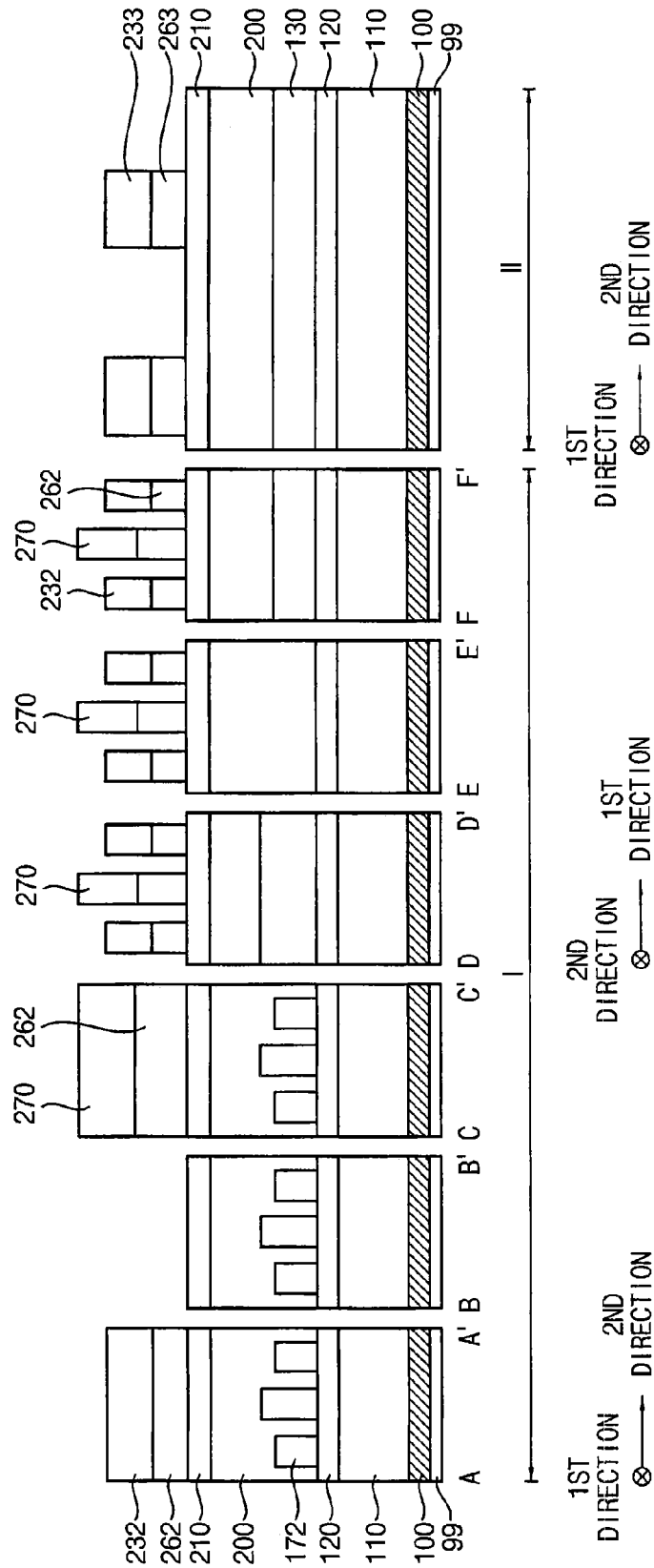


FIG. 15

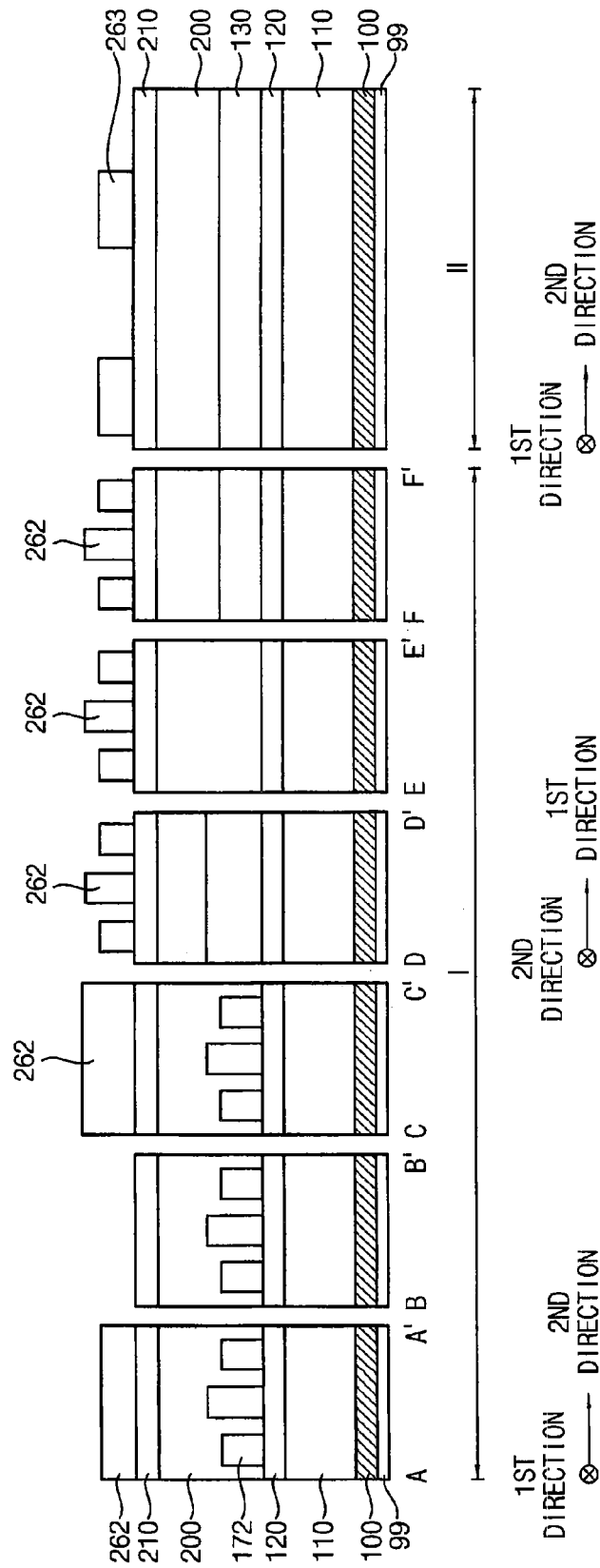


FIG. 16

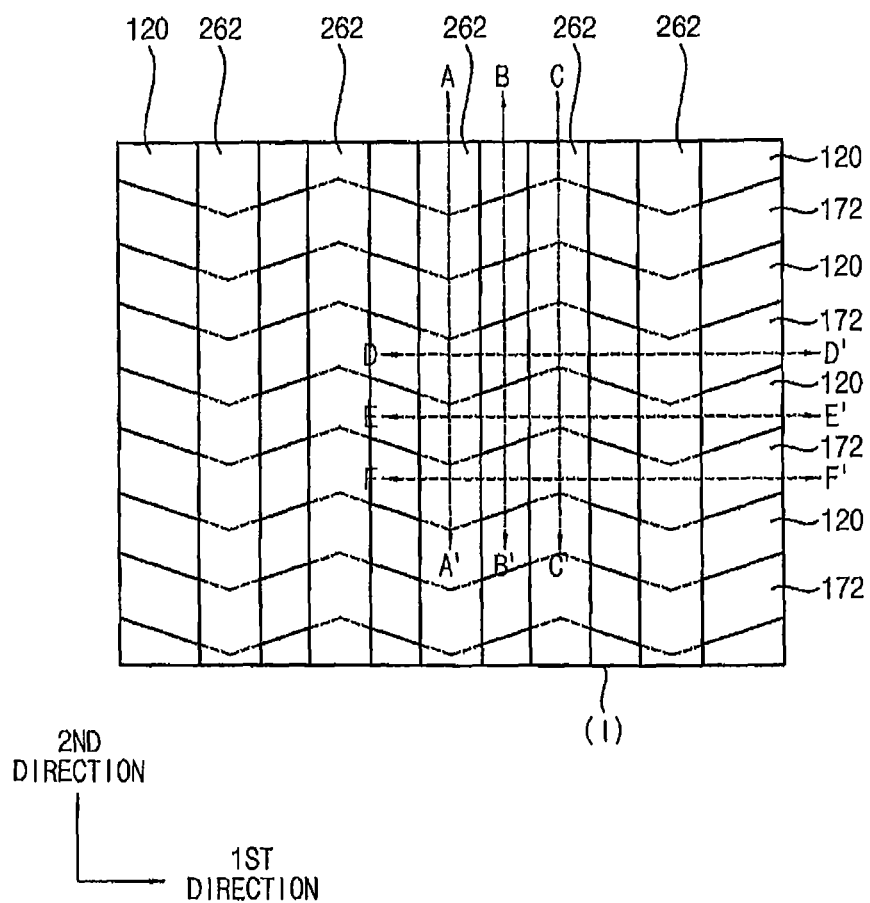


FIG. 17

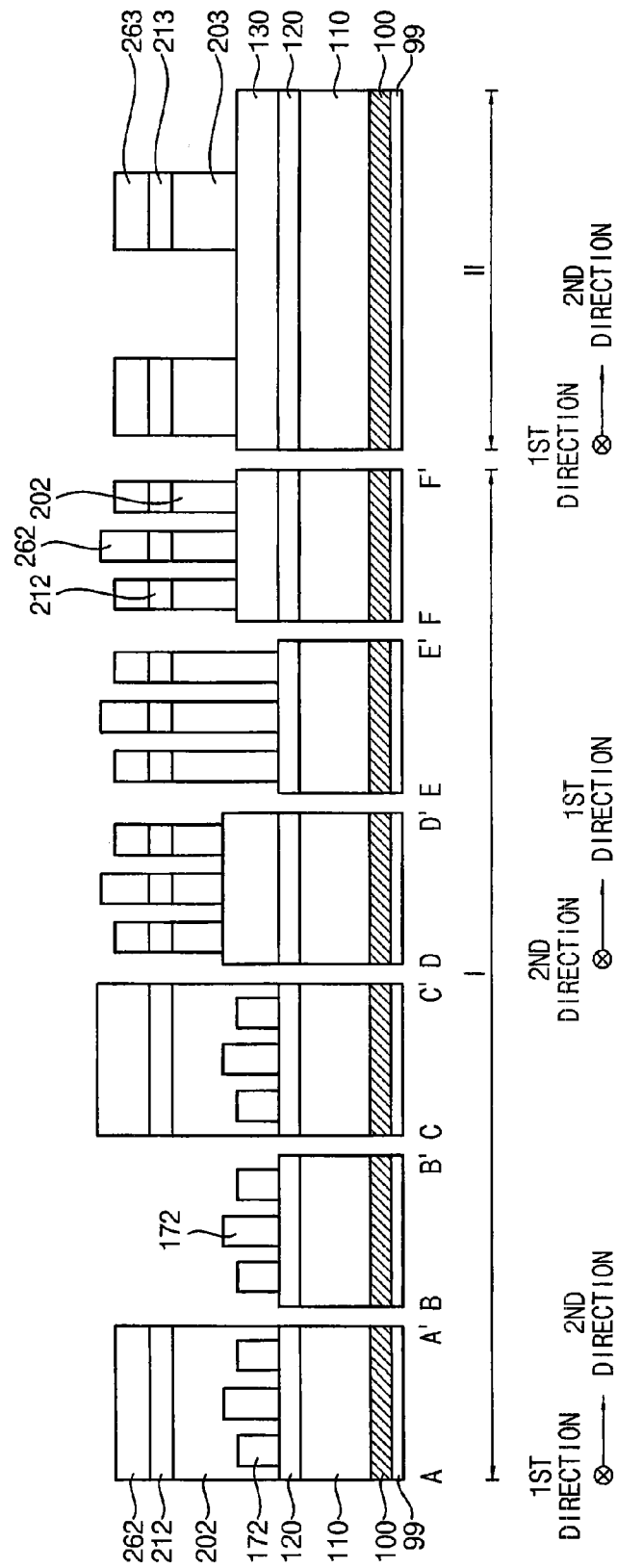


FIG. 18

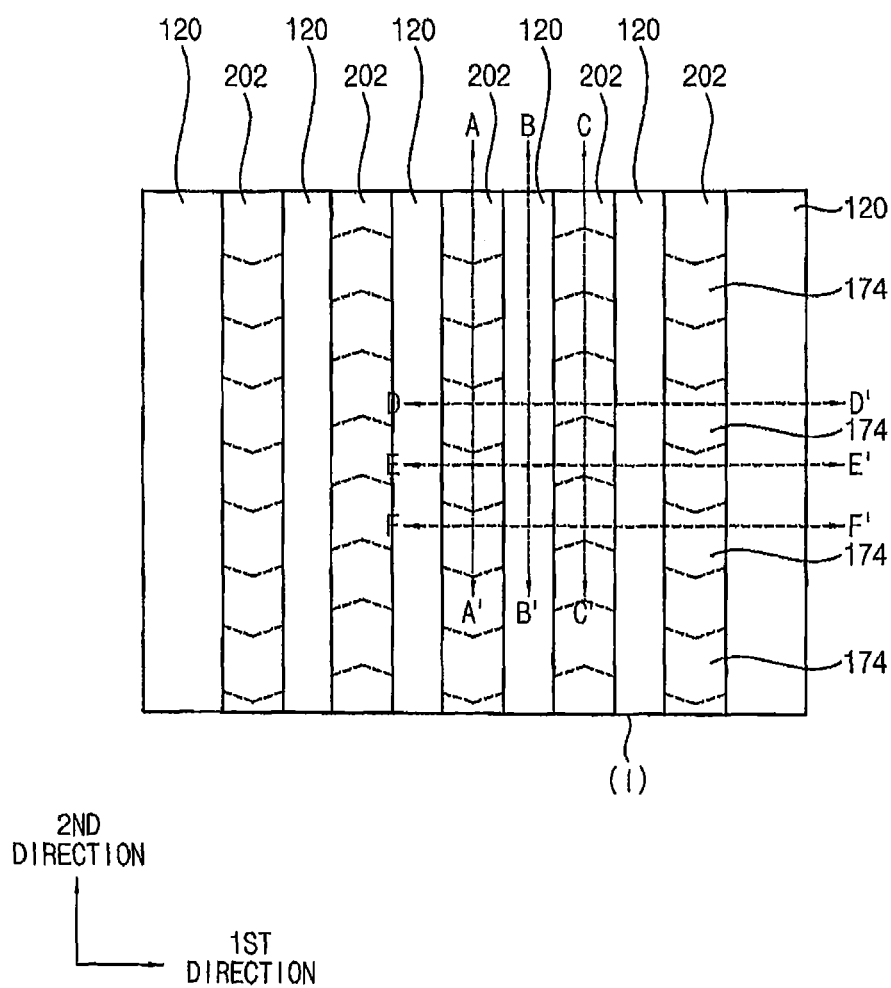


FIG. 19

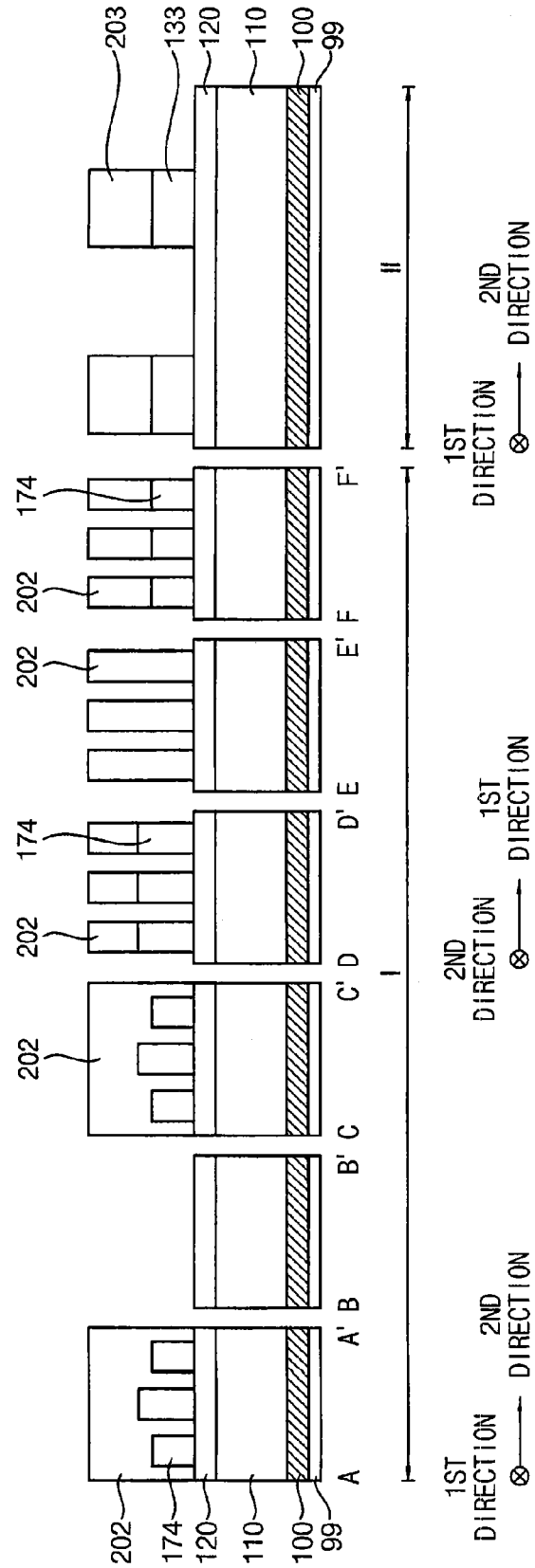


FIG. 20

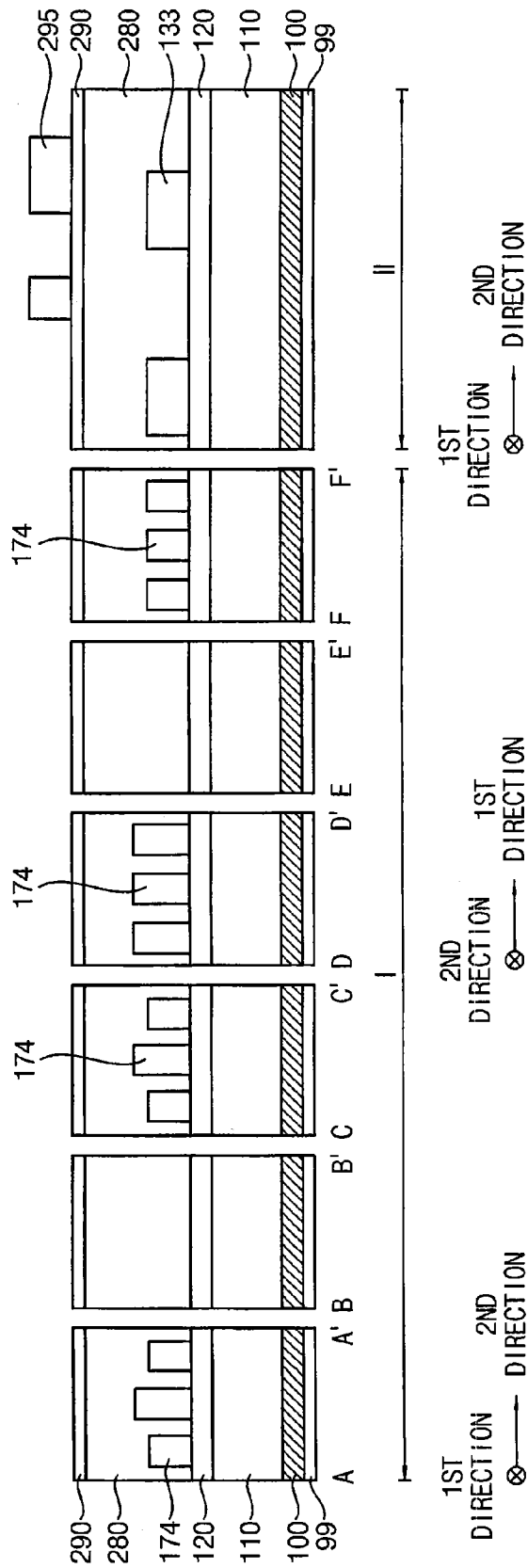


FIG. 21

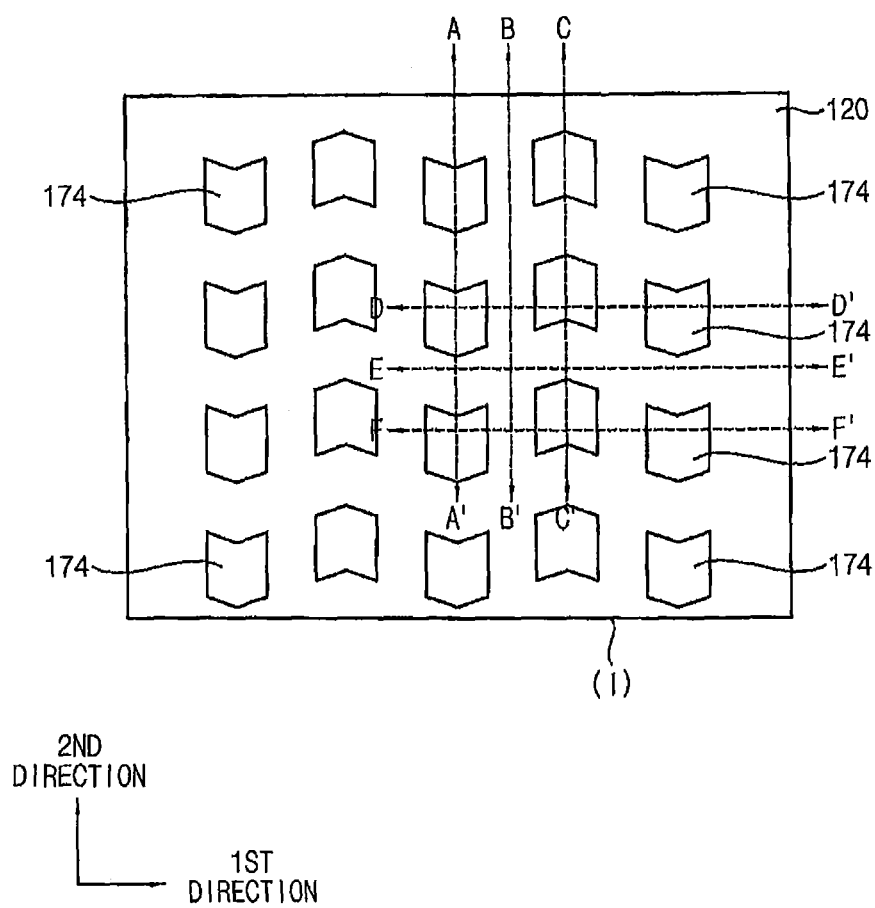


FIG. 22

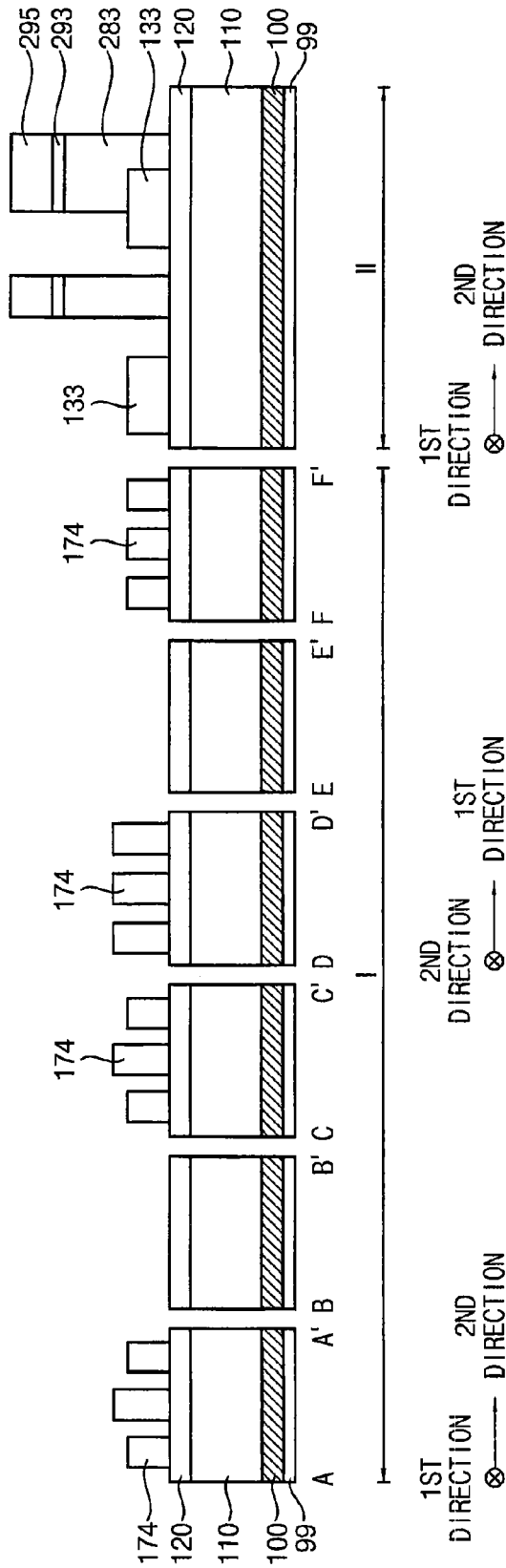


FIG. 23

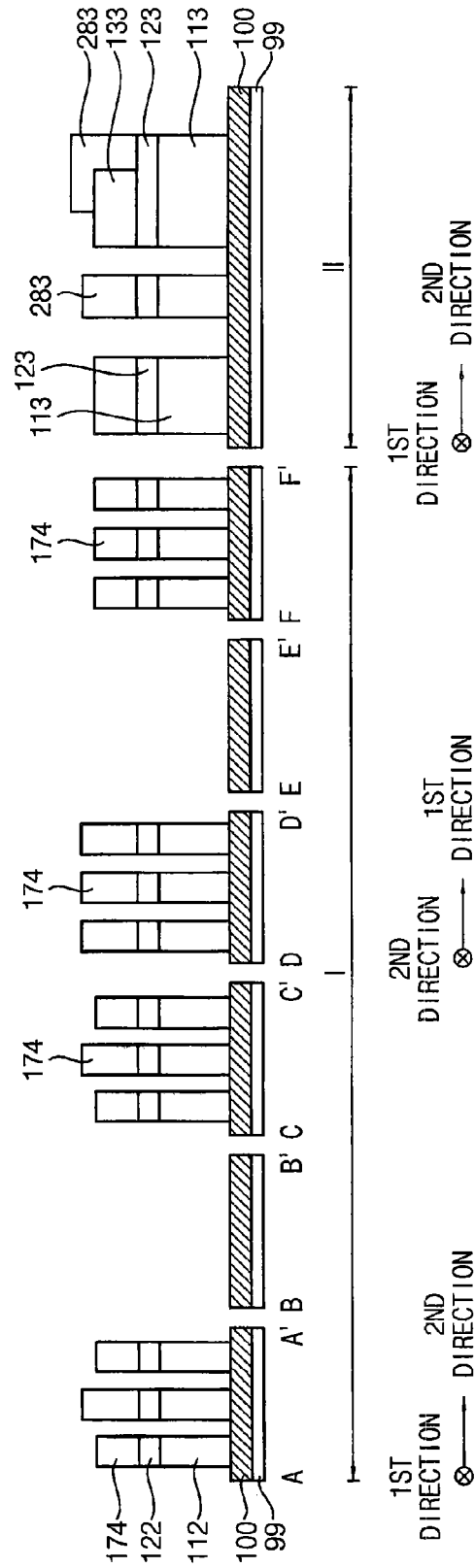


FIG. 24

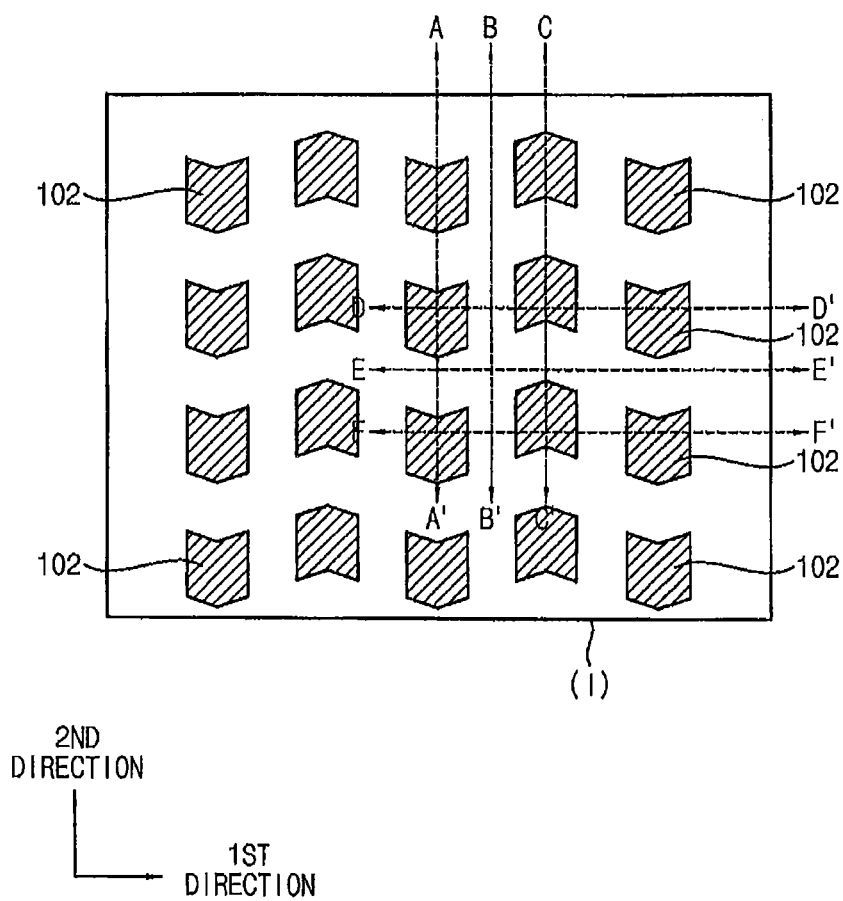


FIG. 25

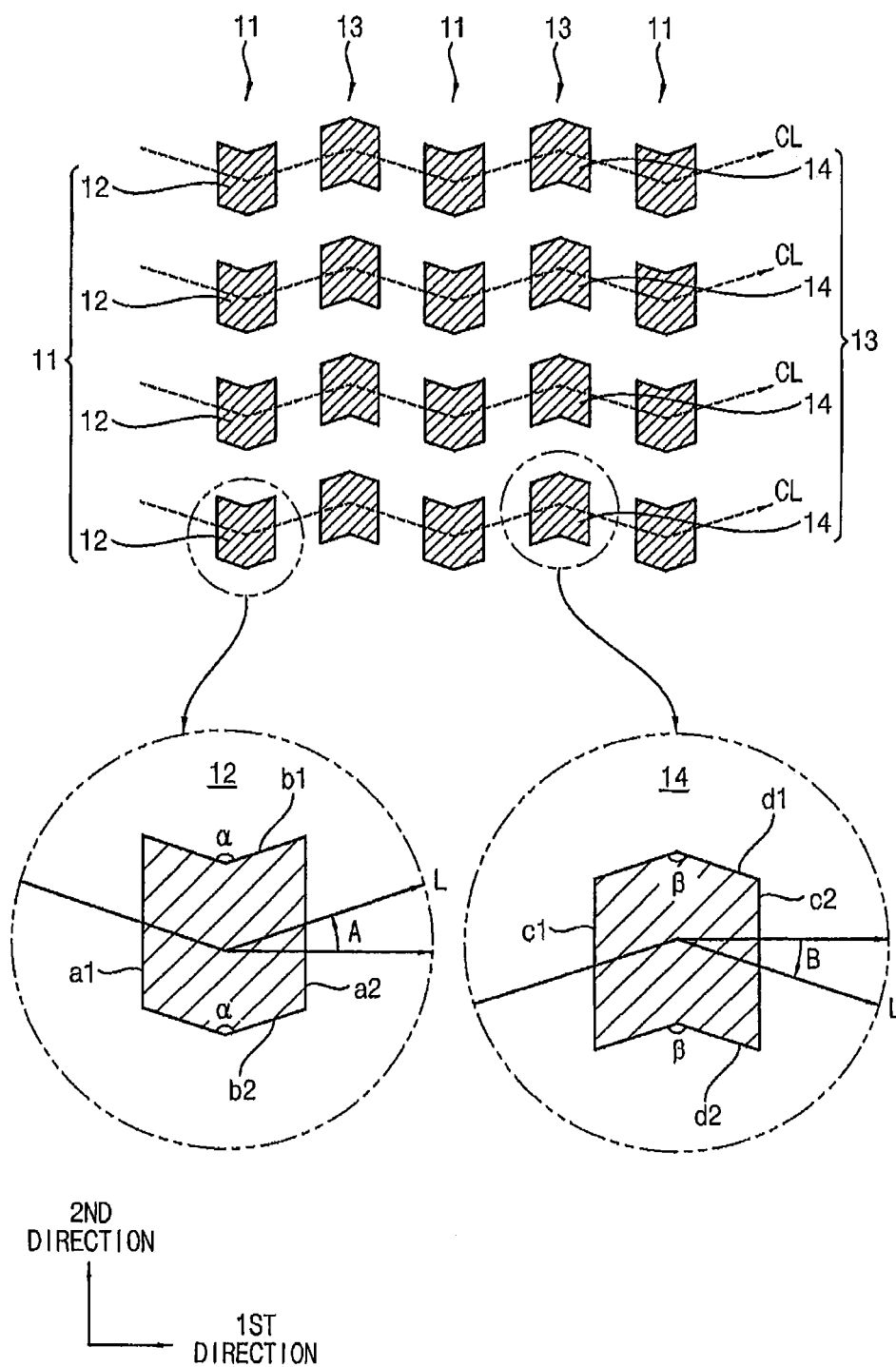


FIG. 26

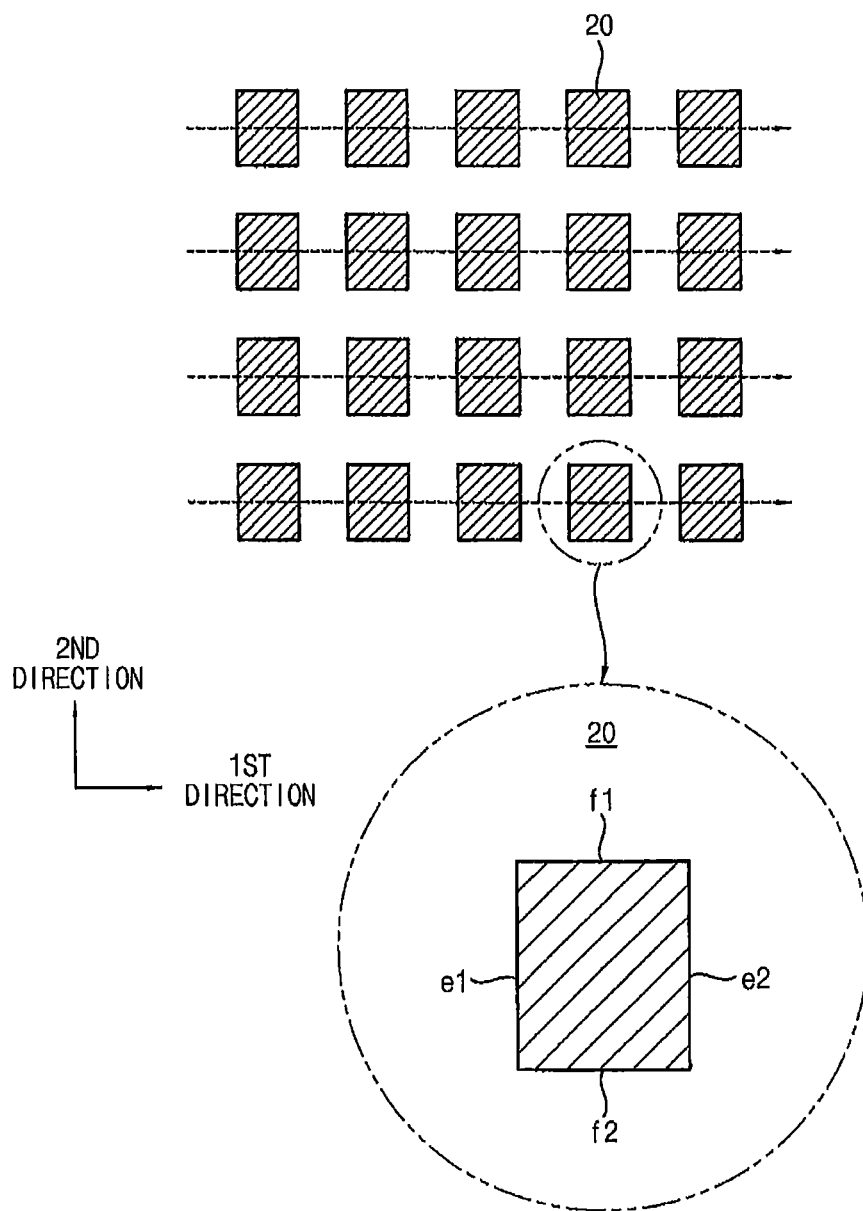


FIG. 27

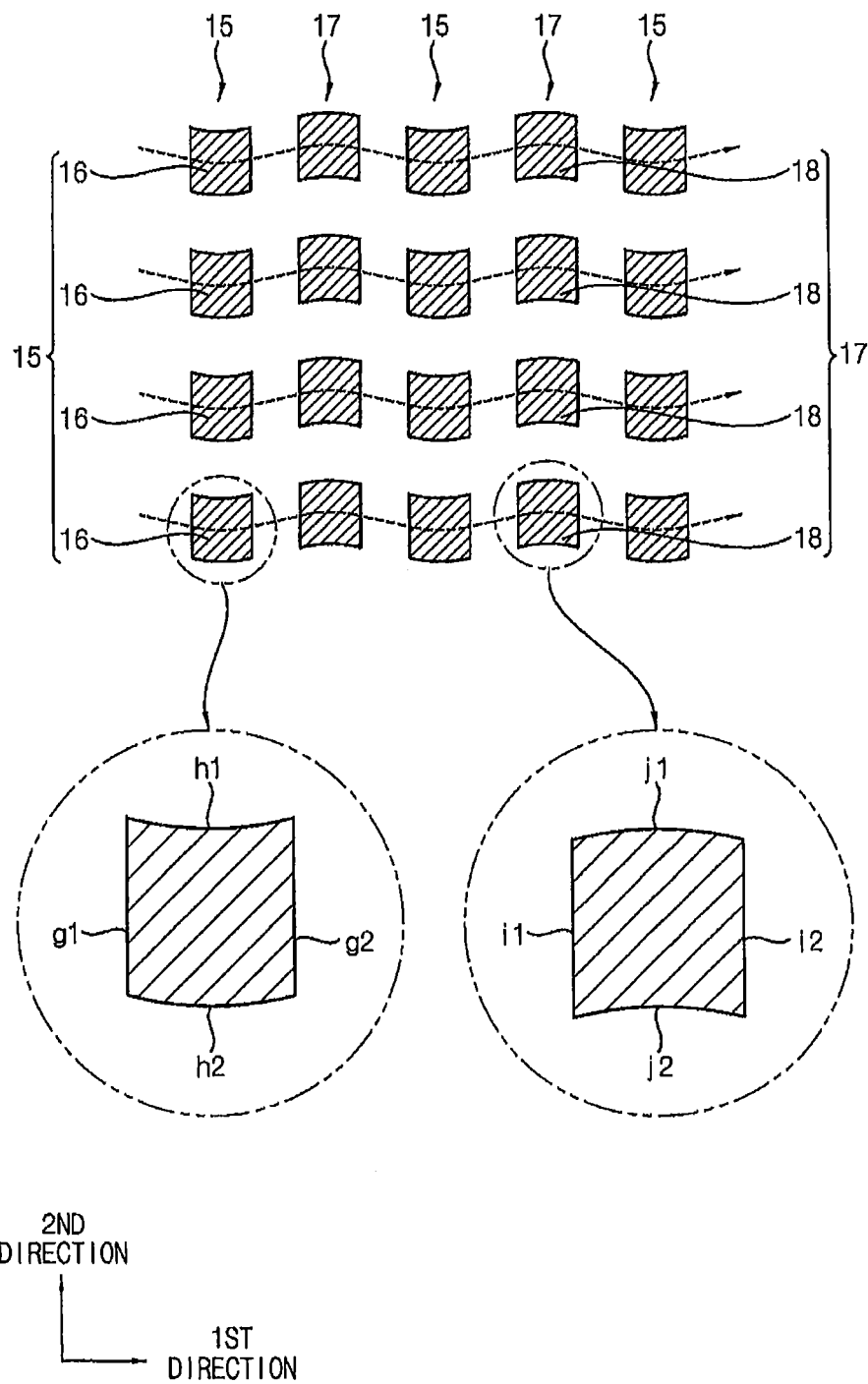


FIG. 28

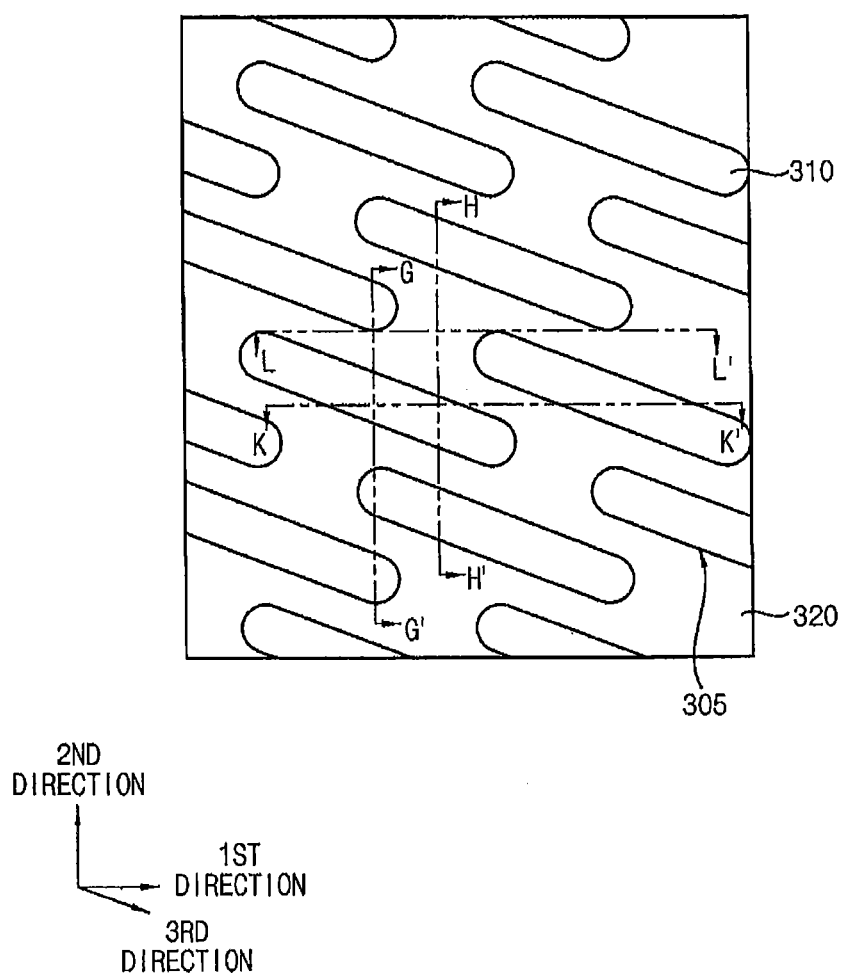


FIG. 29

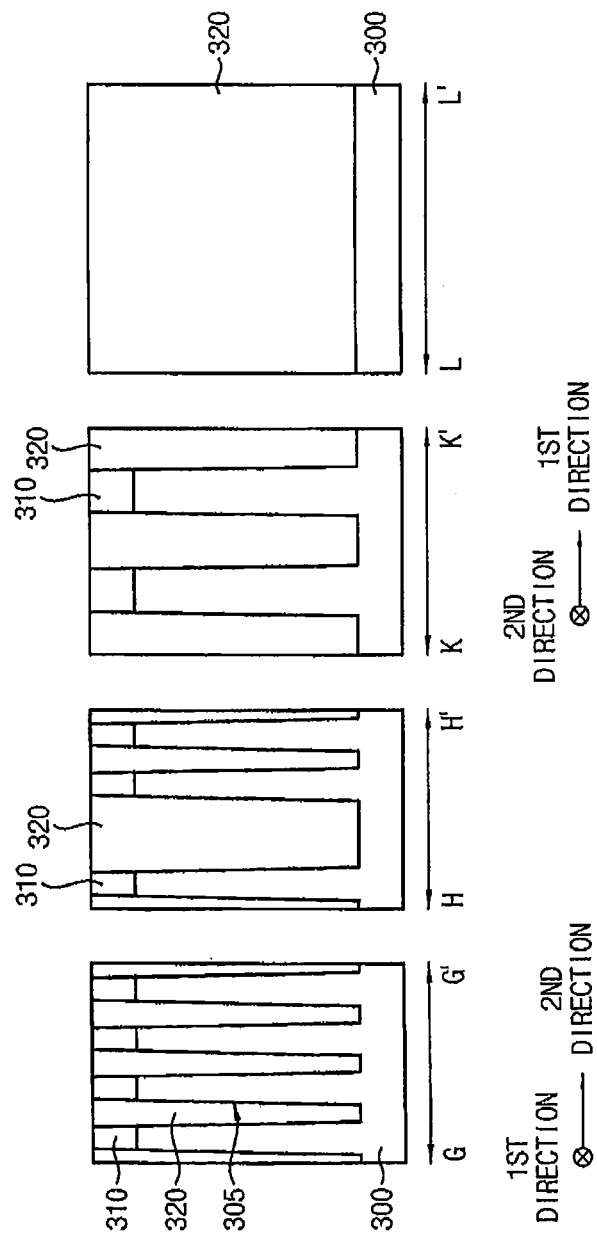


FIG. 30

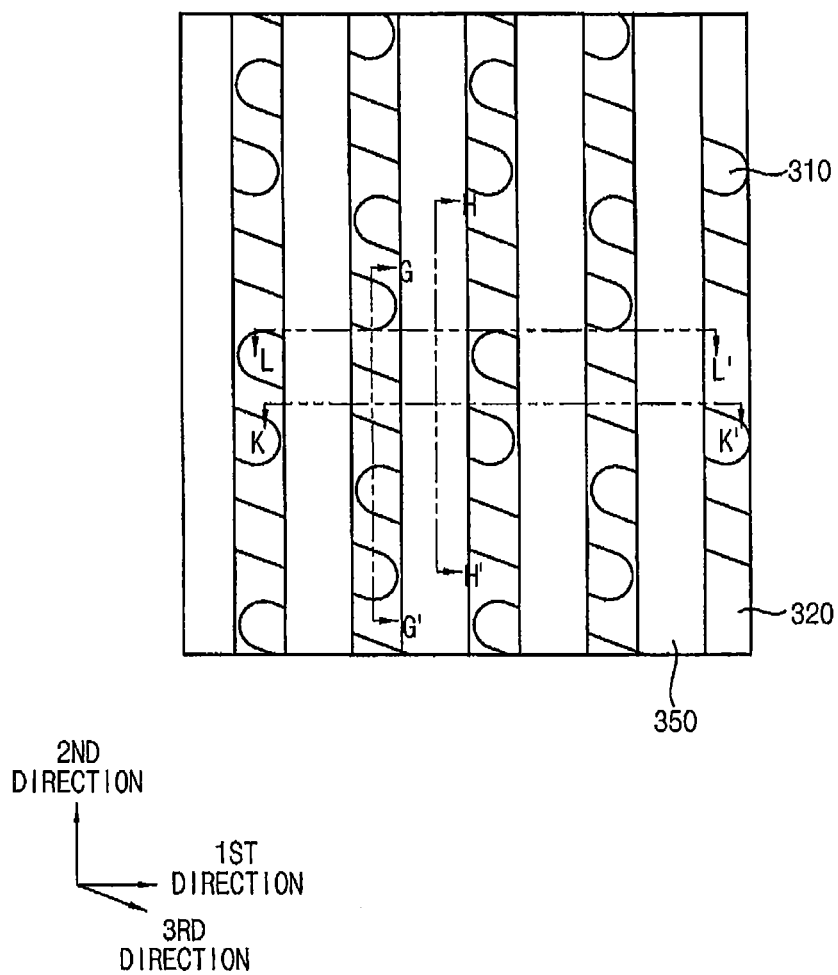


FIG. 31

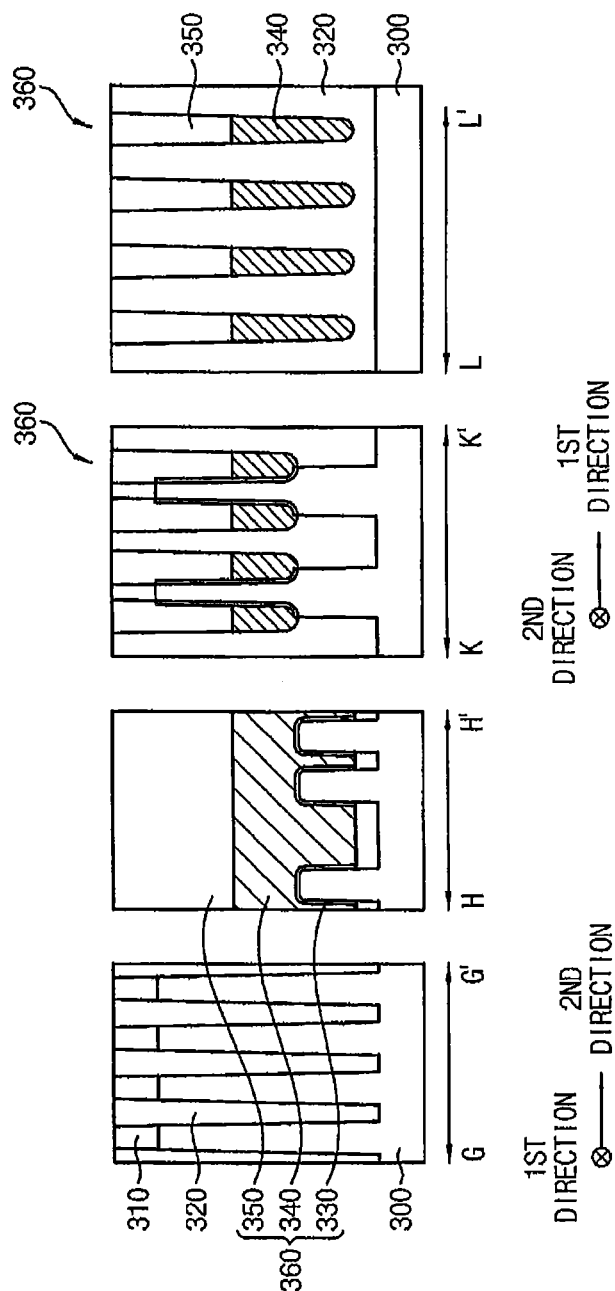


FIG. 32

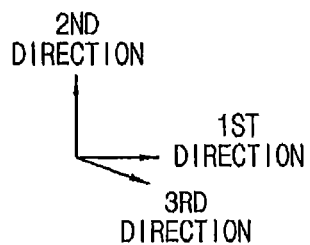
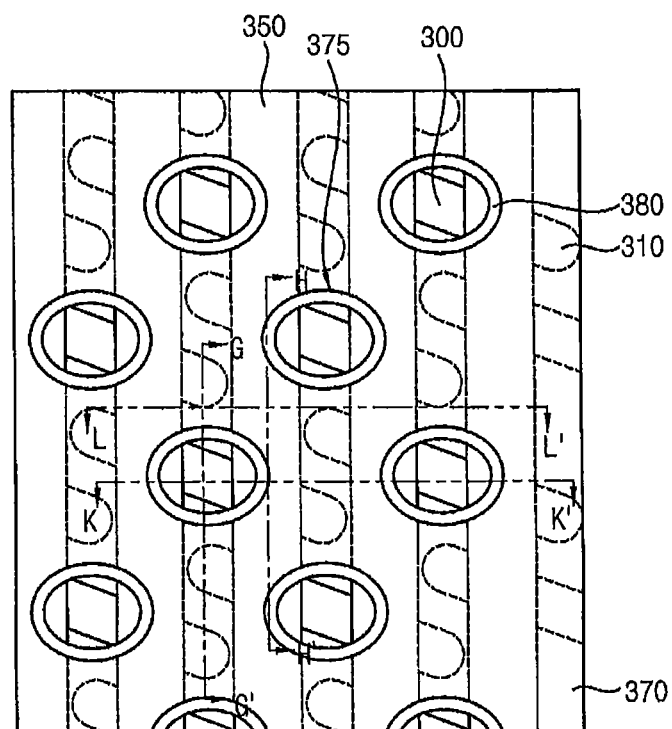


FIG. 33

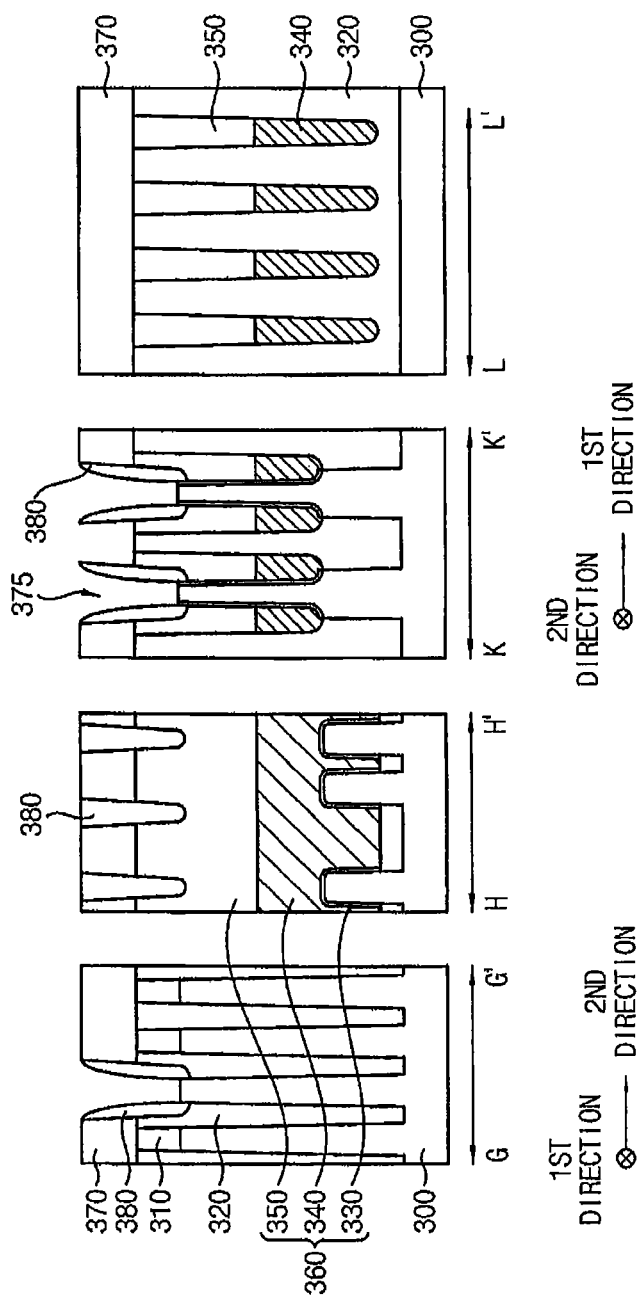


FIG. 34

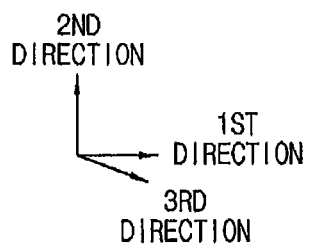
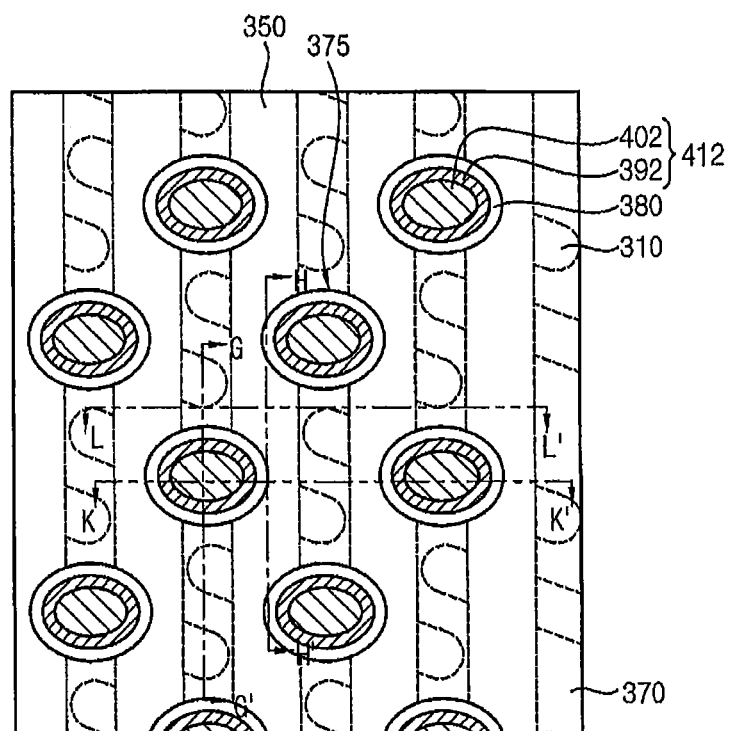


FIG. 35

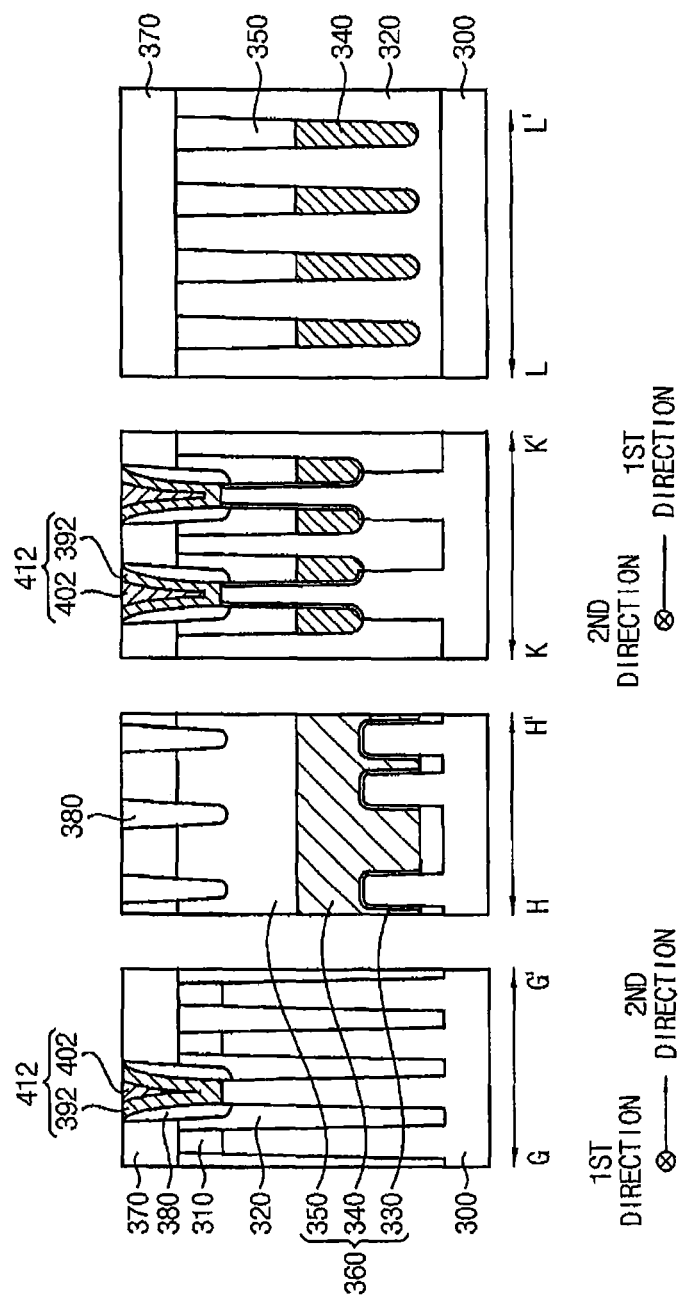


FIG. 37

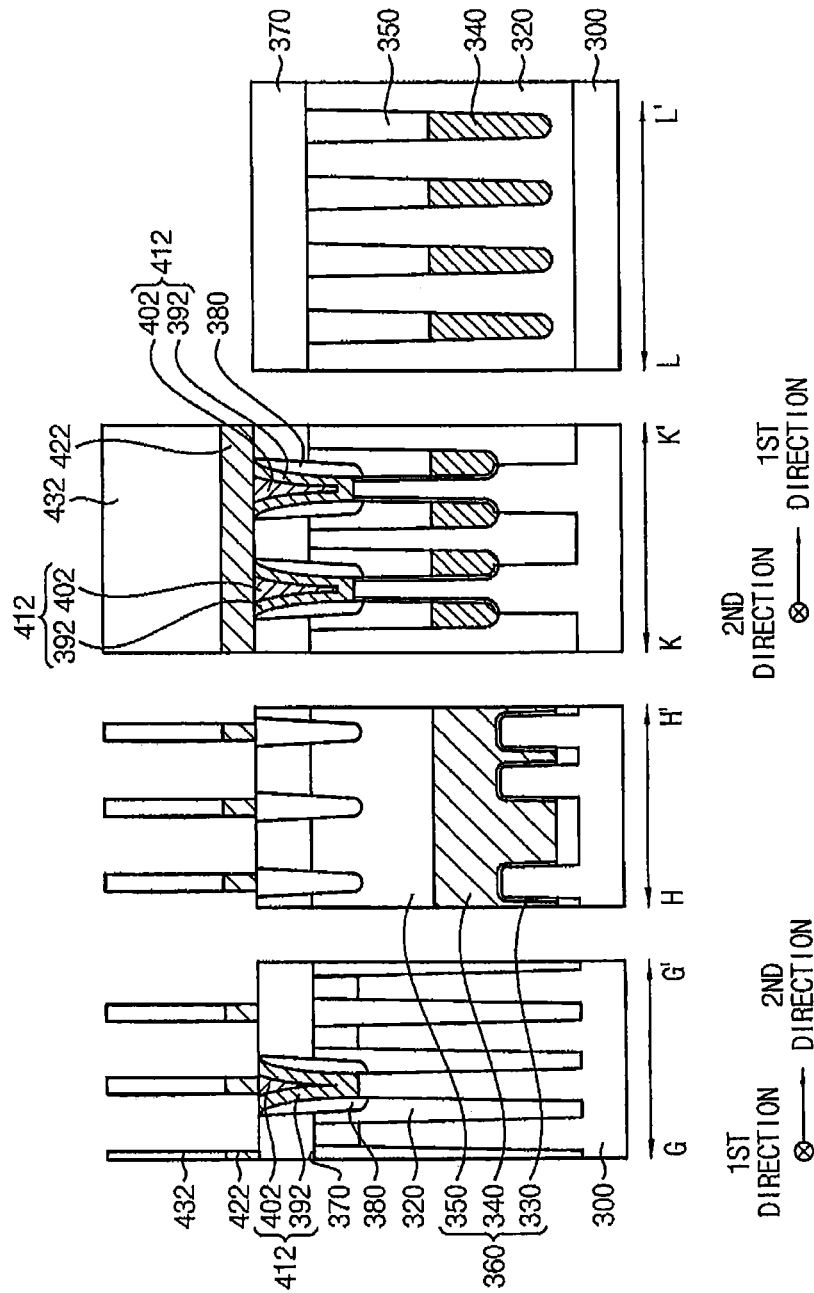


FIG. 38

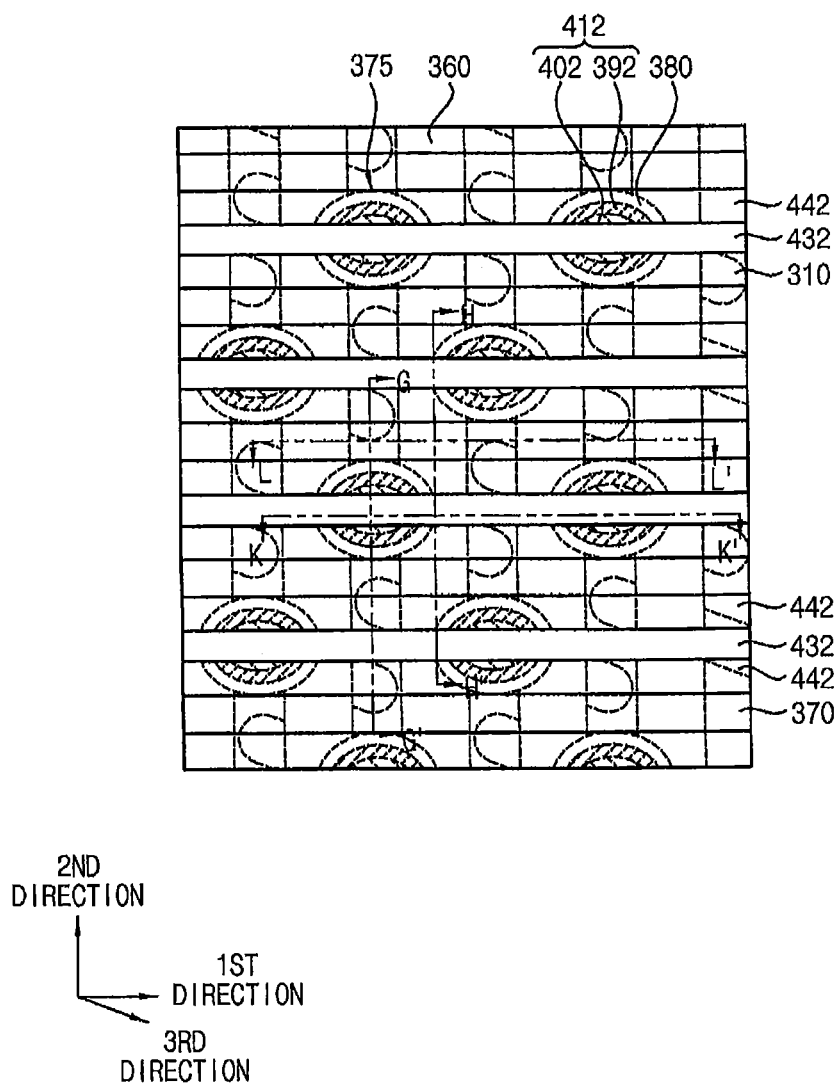


FIG. 39

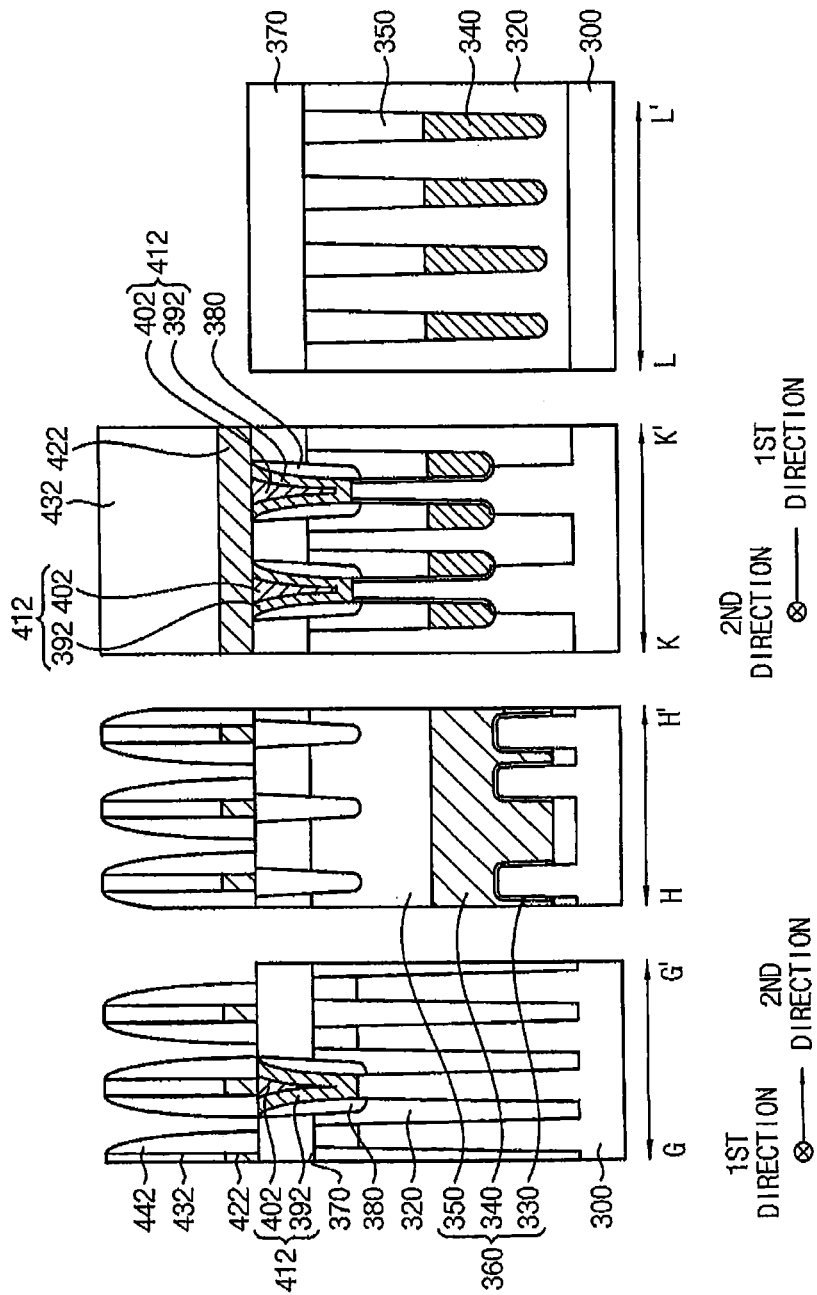


FIG. 40

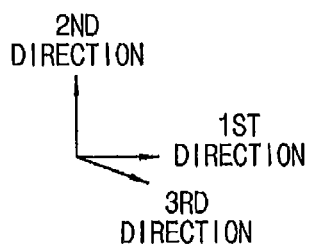
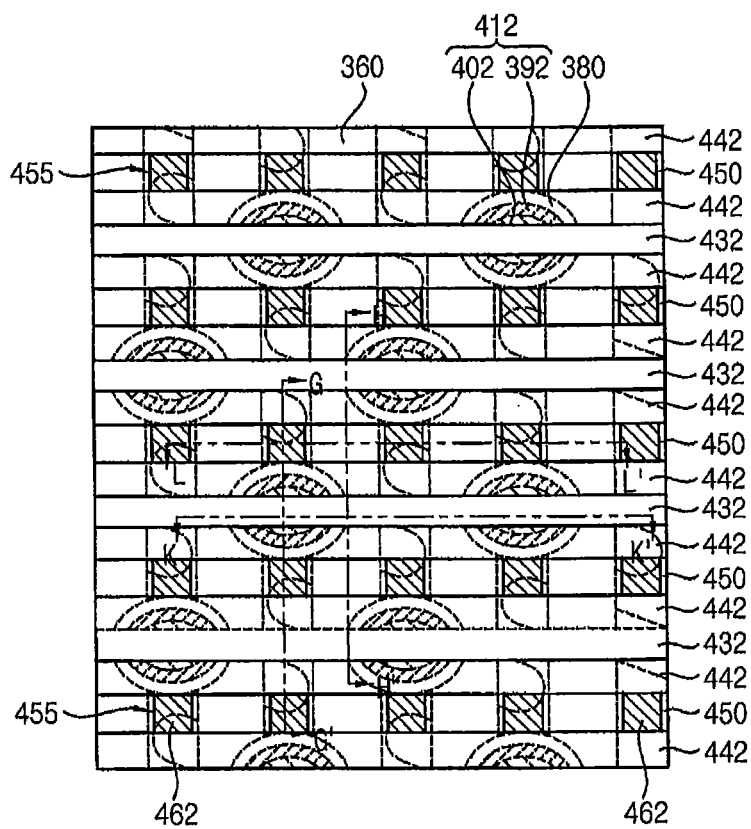


FIG. 41

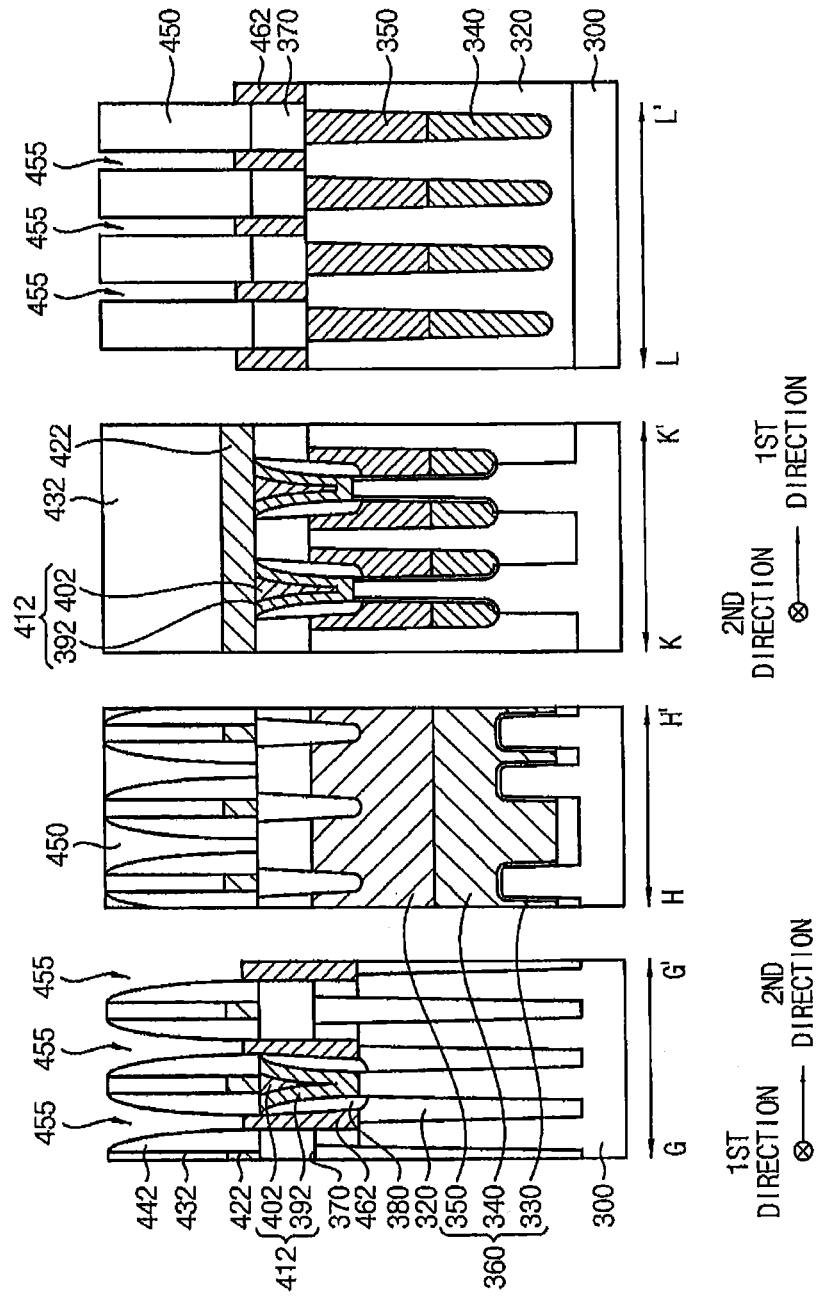


FIG. 42

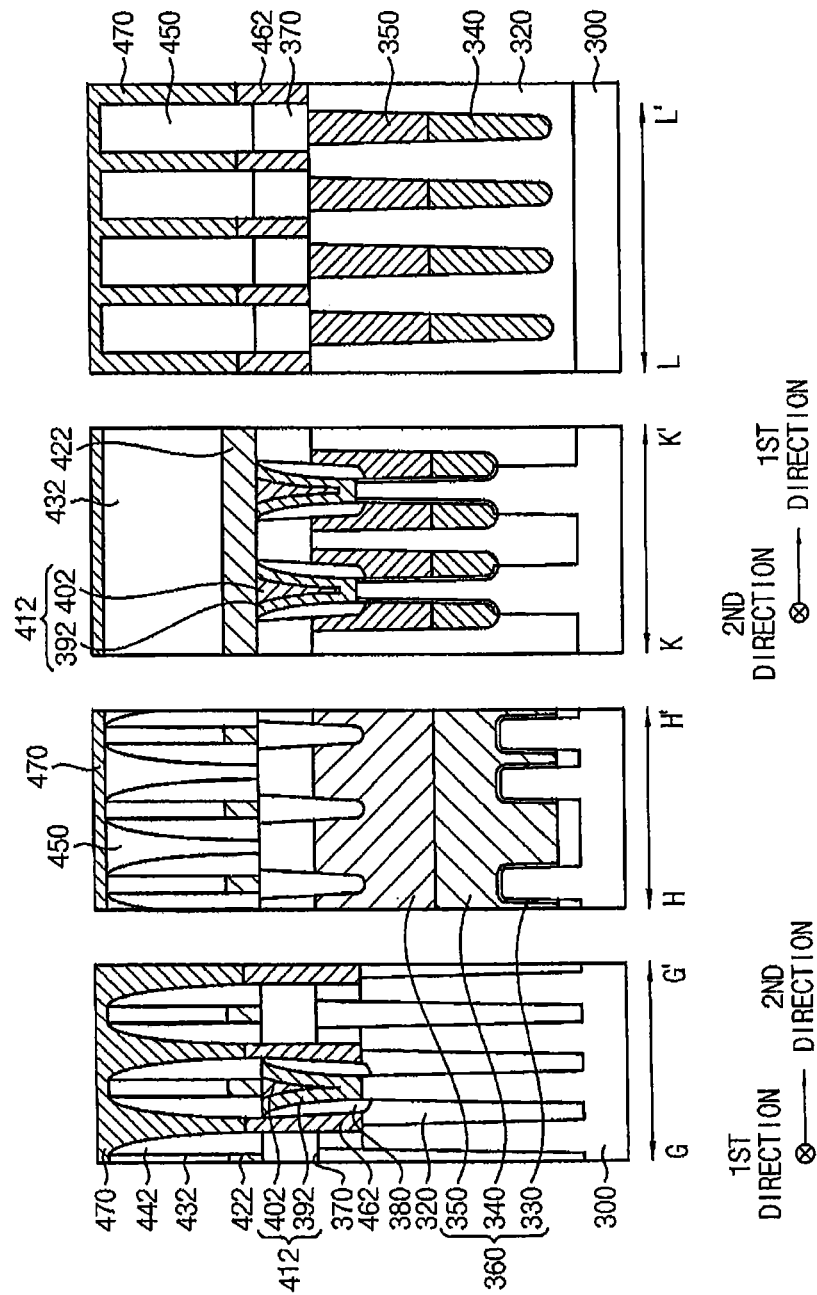


FIG. 43

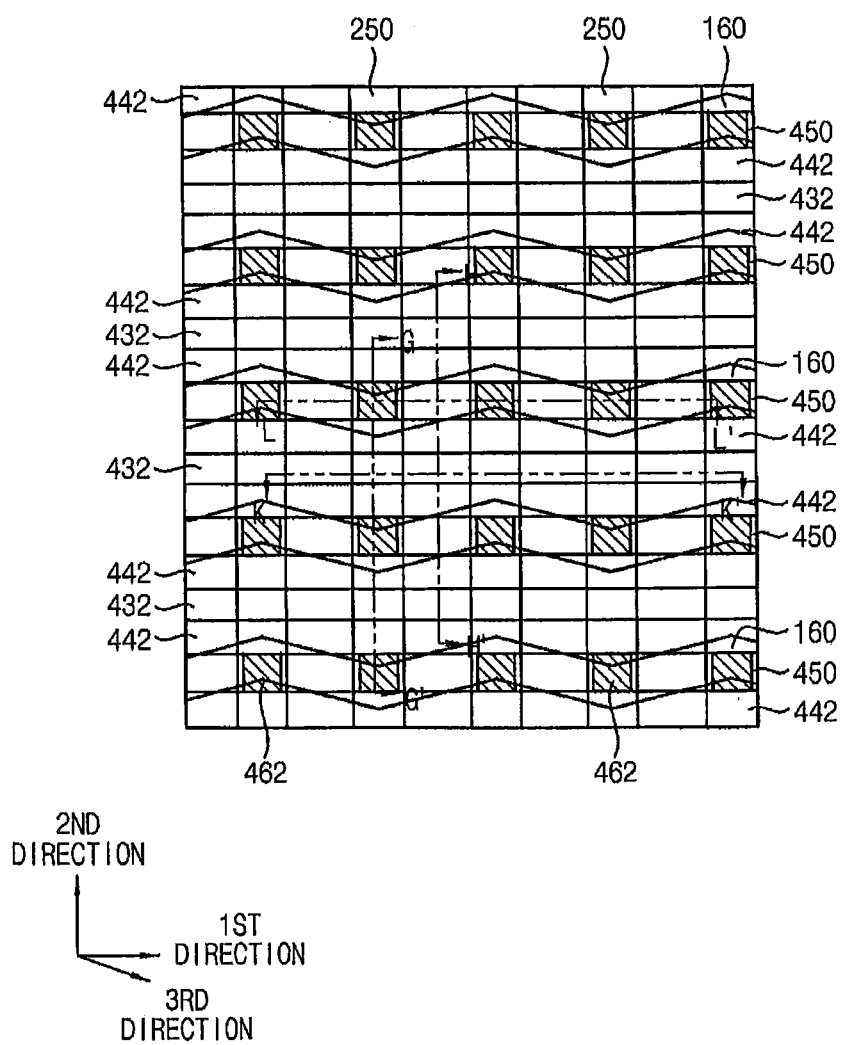


FIG. 44

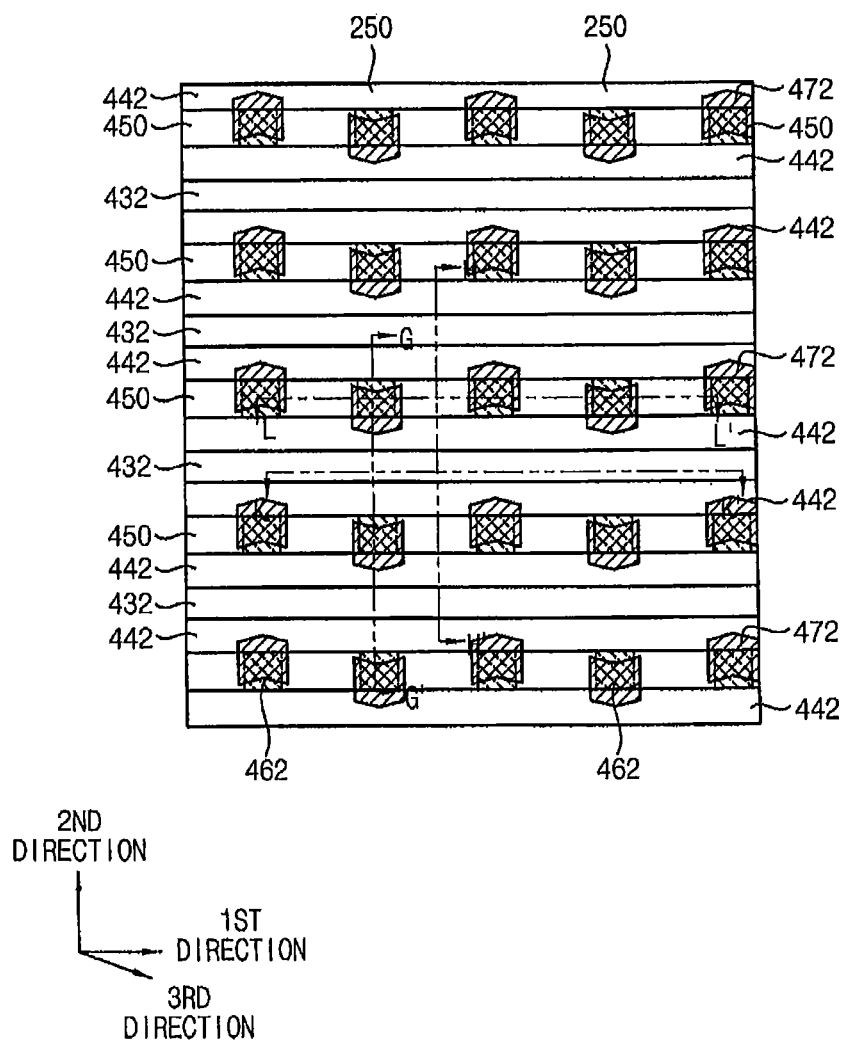
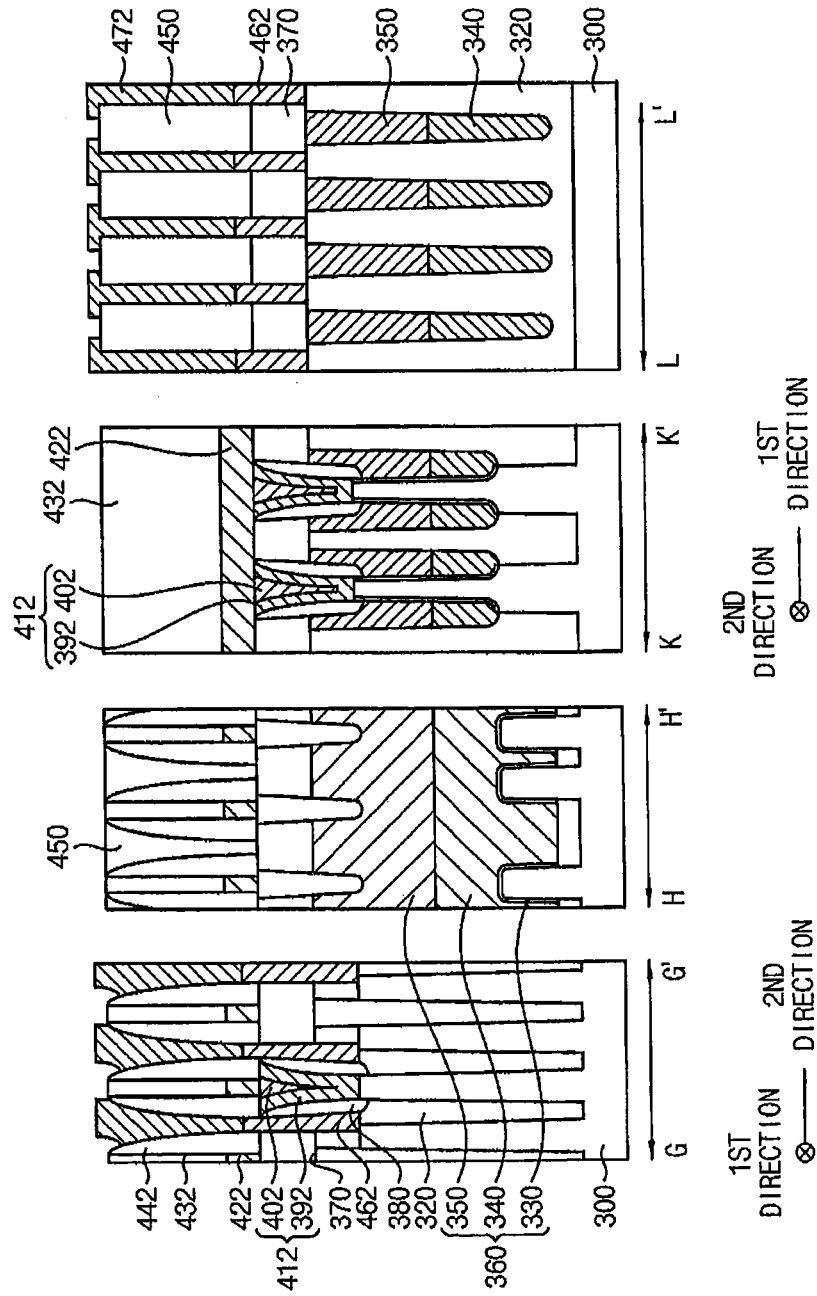


FIG. 45



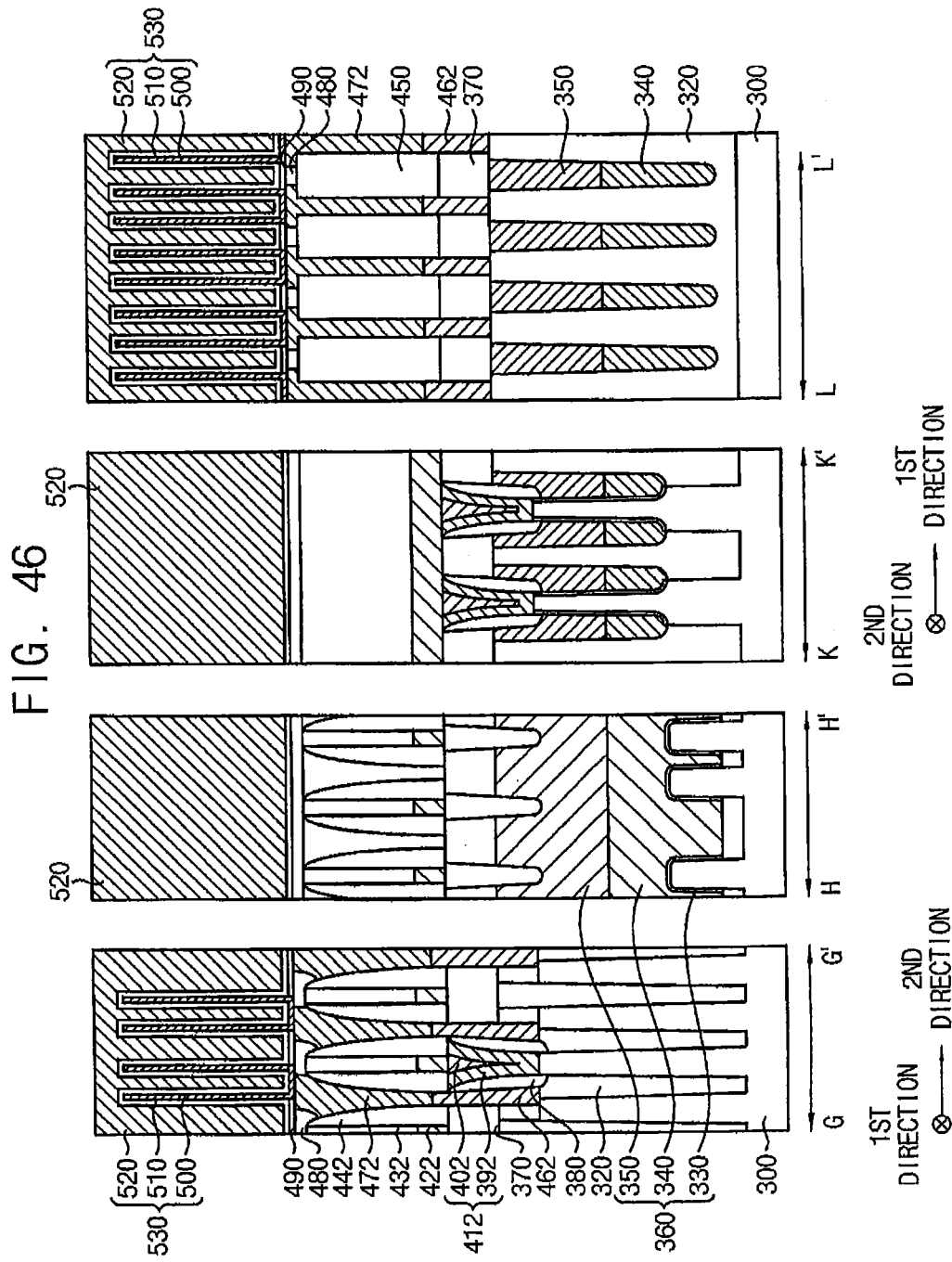


FIG. 47

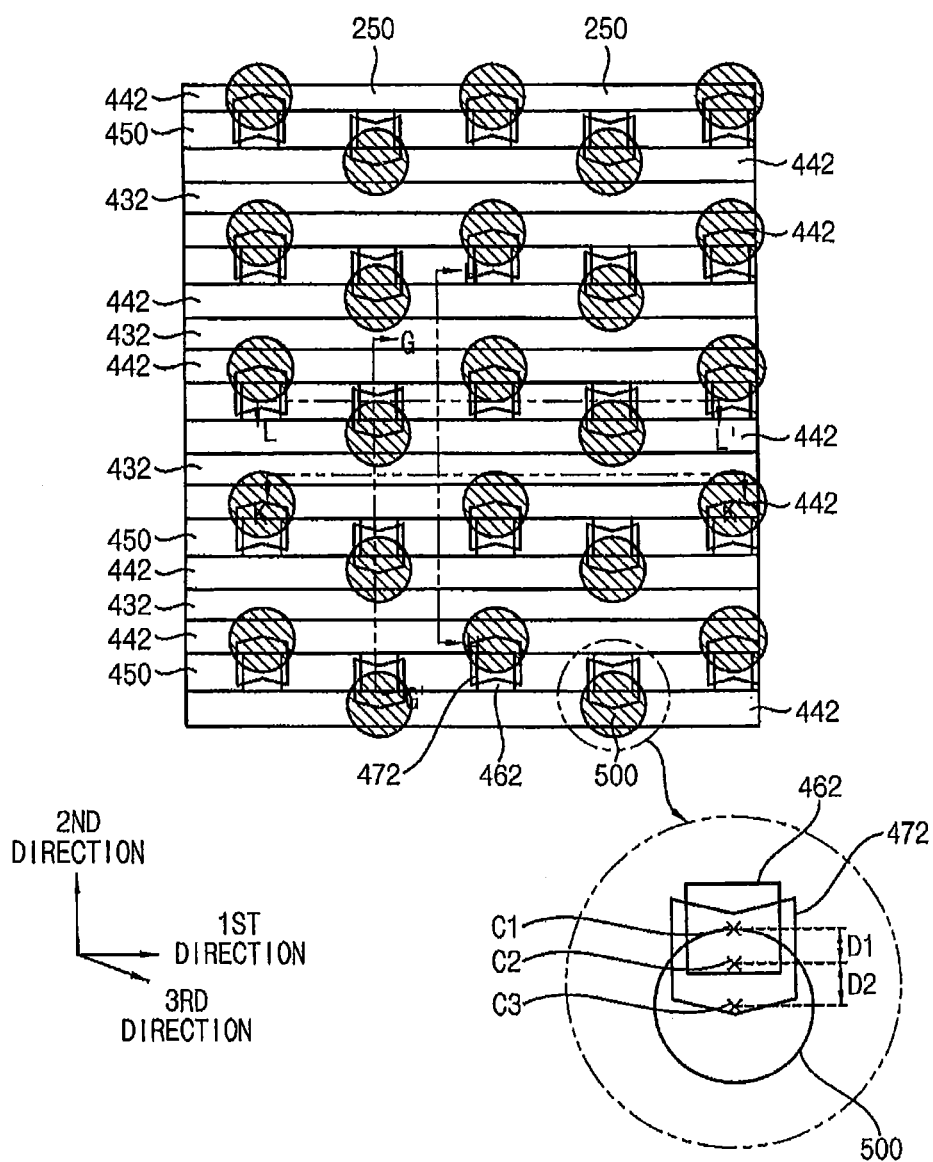


FIG. 48

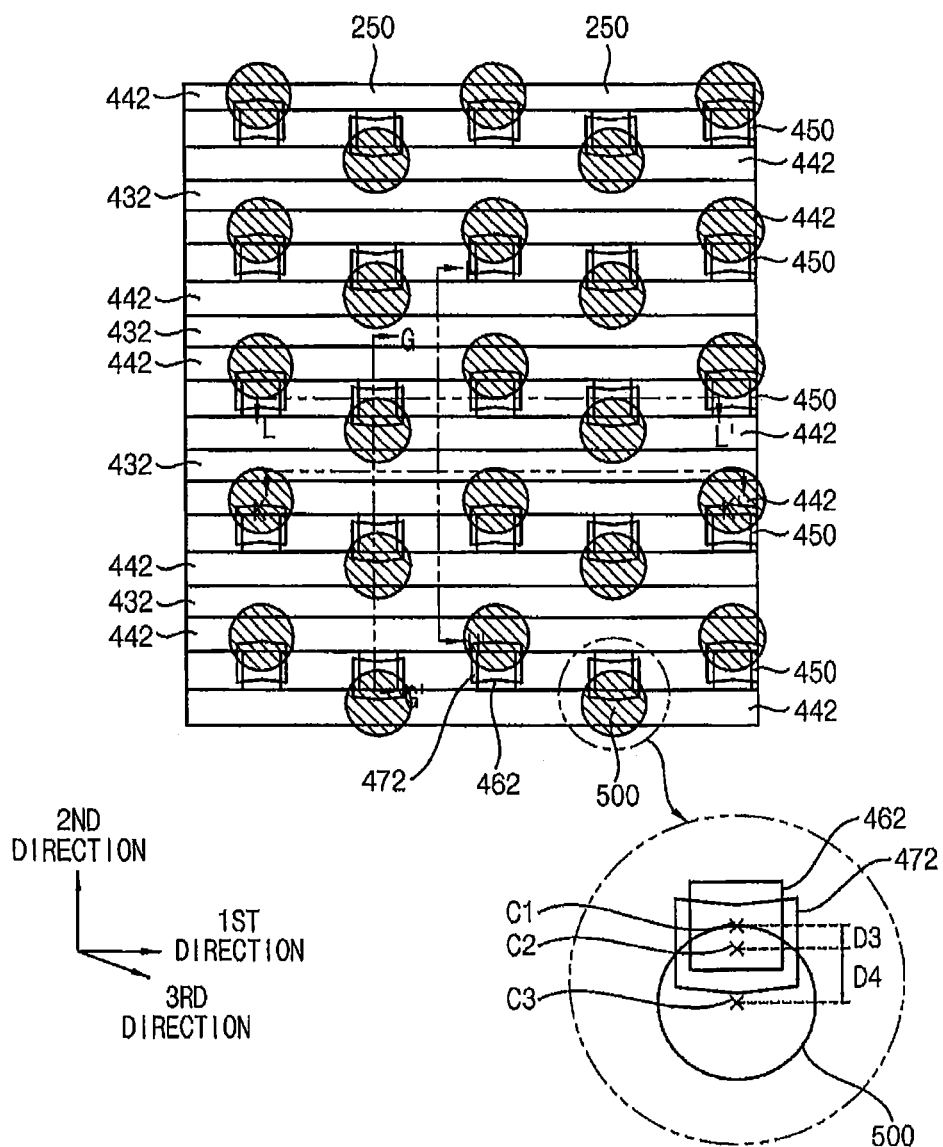


FIG. 49

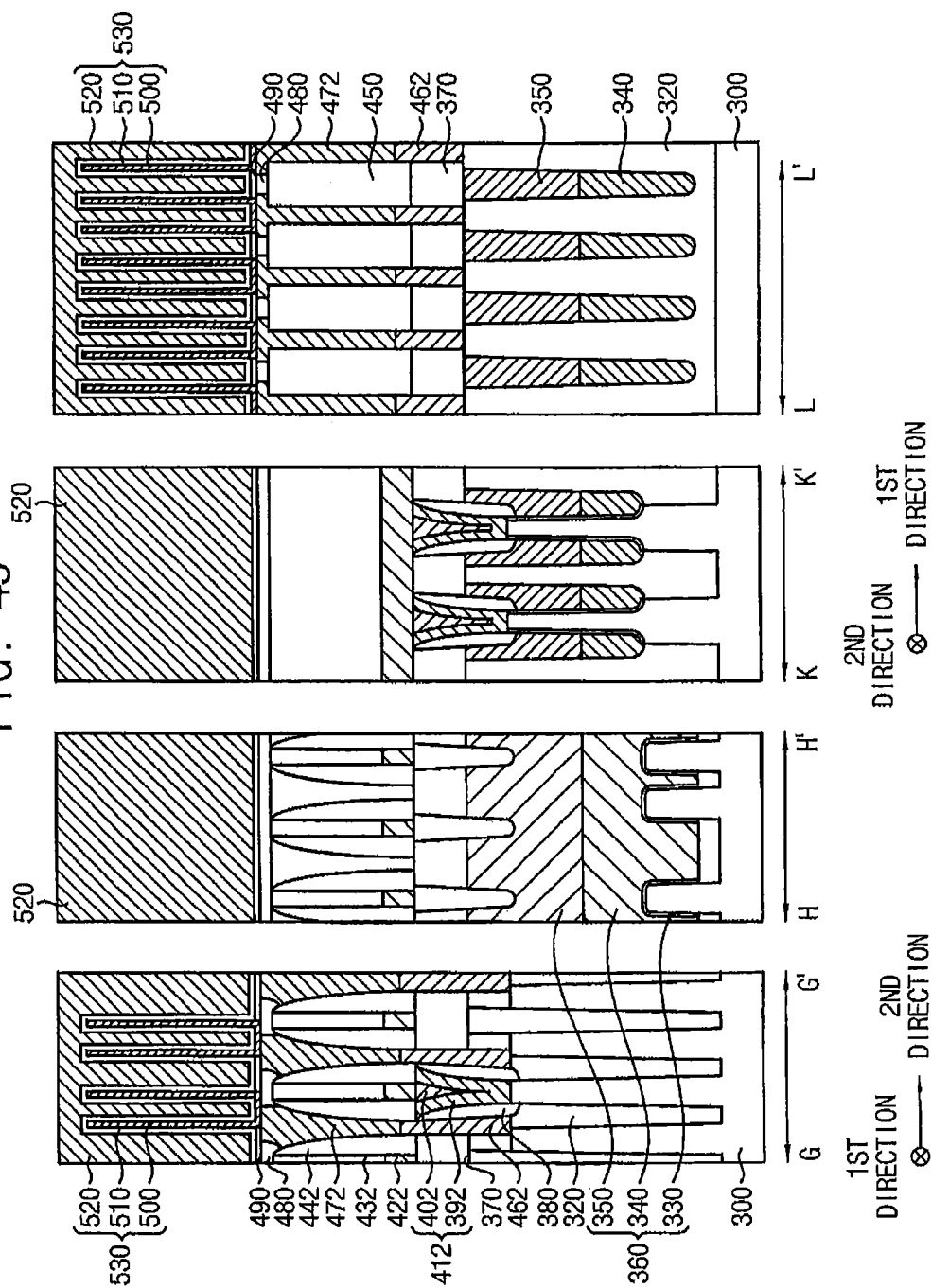


FIG. 50

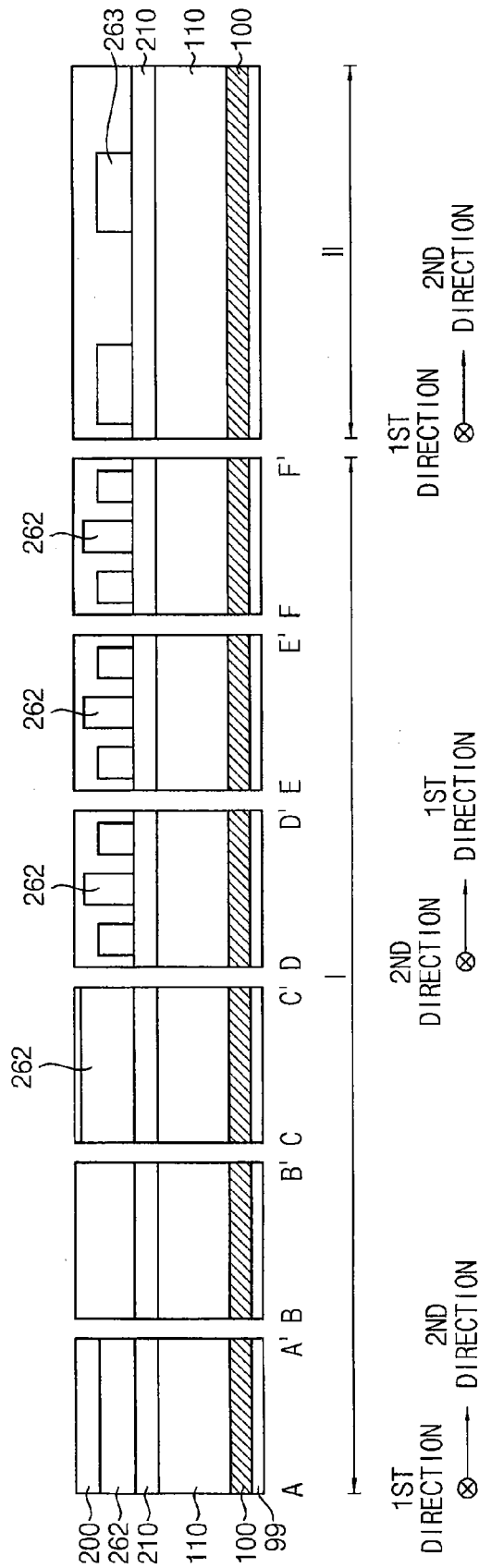
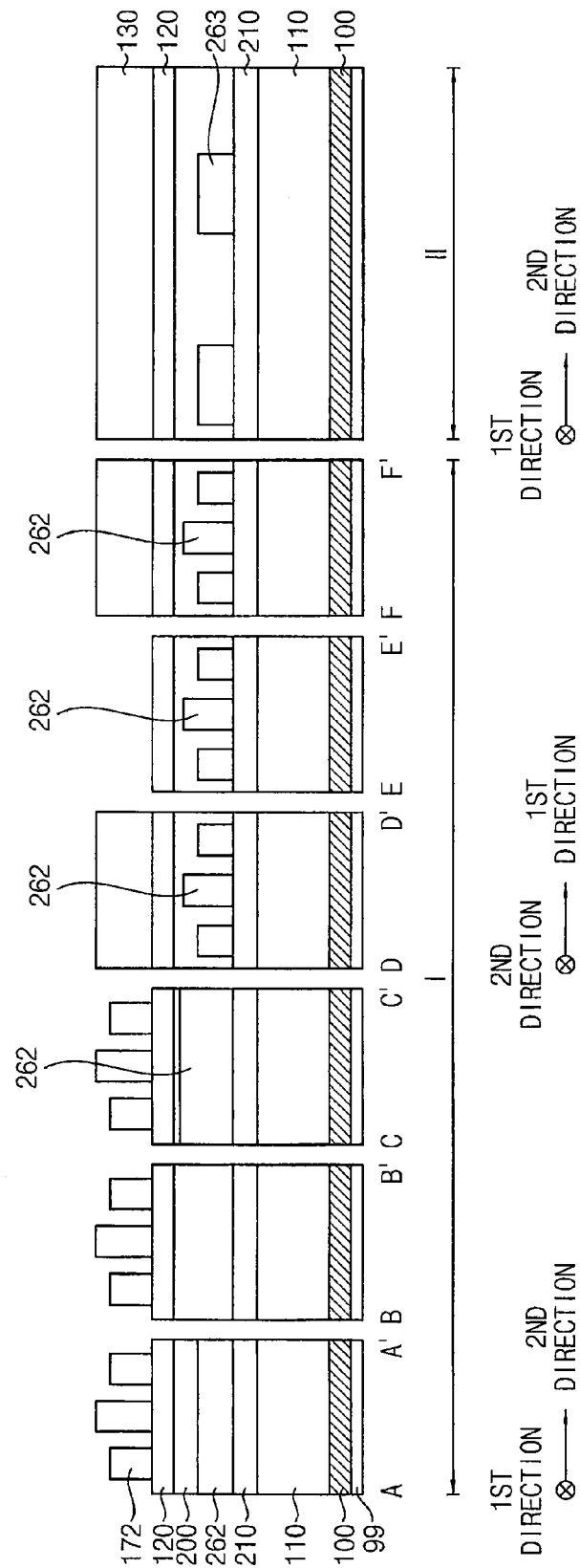


FIG. 51



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METHODS OF FORMING ELECTRONIC DEVICES HAVING PADS USING FIRST AND SECOND MASKS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of priority as a continuation of U.S. application Ser. No. 14/105,581, filed on Dec. 13, 2013, which claims priority under 35 USC §119 to Korean Patent Application No. 10-2013-0070688, filed on Jun. 20, 2013 in the Korean Intellectual Property Office (KIPO). The disclosures of both of the above referenced applications are hereby incorporated herein by reference in their entireties.

BACKGROUND

A self-align patterning method for forming patterns may include forming a first layer on a substrate, and forming a plurality of first hard mask patterns on the first layer. A sacrificial layer is formed on top surfaces and sidewalls of the first hard mask patterns, thereby forming a gap between respective facing portions of the sacrificial layer on the sidewalls of the first hard mask patterns. A second hard mask pattern is formed in the gap, the sacrificial layer is etched using the second hard mask pattern as a mask to expose the first hard mask patterns, the first layer is exposed using the exposed first hard mask patterns and the second hard mask pattern. The exposed first layer is then etched using the first and second hard mask patterns.

Such self-aligned patterning methods are discussed, for example, in U.S. Pat. No. 7,615,496 to Lee et al., entitled "Method of Forming Pad Patterns Using Self-Aligned Double Patterning Method, Pad Pattern Layout Formed Using the Same, And Method Of Forming Contact Holes Using Self-Aligned Double Patterning Method," the disclosure of which is hereby incorporated herein in its entirety by reference.

SUMMARY

According to some embodiments, a method of forming an electronic device may include providing a pad layer on a substrate, and forming a plurality of spaced apart first masks on the pad layer. Each of the first masks may define a non-linear pattern extending along a respective axis in a first direction. A plurality of spaced apart second masks may be formed on the pad layer extending in a second direction different than the first direction, wherein each of the second masks crosses each of the first masks. The pad layer may be patterned using the plurality of spaced apart first masks and the plurality of spaced apart second masks to form a plurality of spaced apart pads on the substrate.

Forming the plurality of spaced apart first masks may precede forming the plurality of spaced apart second masks. Moreover, patterning the pad layer may include patterning the plurality of spaced apart first masks using the plurality of spaced apart second masks, removing the plurality of spaced apart second masks to provide a plurality of pad masks after patterning the plurality of spaced apart first masks, patterning the pad layer using the plurality of pad masks to form the plurality of spaced apart pads, and removing the pad masks after patterning the pad layer.

Forming the plurality of spaced apart second masks may precede forming the plurality of spaced apart first masks. Moreover, patterning the pad layer may include patterning

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the plurality of spaced apart second masks using the plurality of spaced apart first masks, removing the plurality of spaced apart first masks to provide a plurality of pad masks after patterning the plurality of spaced apart second masks, patterning the pad layer using the plurality of pad masks to form the plurality of spaced apart pads, and removing the pad masks after patterning the pad layer.

Each of the second masks may cross the plurality of spaced apart first masks linearly.

Each of the second masks may have a non-linear pattern crossing the plurality of spaced apart first masks.

The non-linear pattern may be a periodic pattern extending along the respective axis in the first direction. Each of the second masks may cross each of the first masks at a respective maximum deviation of the first mask from the respective axis.

Forming the plurality of spaced apart first masks may include forming a first plurality of spaced apart patterns, and forming a second plurality of spaced apart patterns that are self-aligned with the first plurality of spaced apart patterns.

The substrate may include a plurality of memory cell transistors, and each of the plurality of spaced apart pads may be electrically coupled to a source/drain region of a respective one of the memory cell transistors. After forming the plurality of pads, a plurality of memory cell capacitors may be formed, wherein each of the memory cell capacitors is electrically coupled to a respective one of the pads.

The second direction may be perpendicular with respect to the first direction.

According to some other embodiments, a method of forming an electronic device may include providing a pad layer on a substrate, and forming a plurality of spaced apart first masks on the pad layer extending in a first direction. Forming the plurality of spaced apart first masks may include forming a first plurality of spaced apart patterns, and forming a second plurality of spaced apart patterns that are self-aligned with the first plurality of spaced apart patterns. A plurality of spaced apart second masks may be formed on the pad layer extending in a second direction different than the first direction, and each of the second masks may cross each of the first masks. The pad layer may be patterned using the plurality of spaced apart first masks and the plurality of spaced apart second masks to form a plurality of spaced apart pads on the substrate.

Each of the first masks may define a non-linear pattern extending along a respective axis in the first direction, and each of the second masks may define a linear pattern extending along a respective axis in the second direction.

Each of the first masks may define a linear pattern extending along a respective axis in the first direction, and each of the second masks may define a non-linear pattern extending along a respective axis in the second direction.

Each of the first masks may define a linear pattern extending along a respective axis in the first direction, and each of the second masks may define a linear pattern extending along a respective axis in the second direction.

Each of the first masks may define a non-linear pattern extending along a respective axis in the first direction, and each of the second masks may define a non-linear pattern extending along a respective axis in the second direction.

Forming the plurality of spaced apart first masks may precede forming the plurality of spaced apart second masks. In addition, patterning the pad layer may include patterning the plurality of spaced apart first masks using the plurality of spaced apart second masks, removing the plurality of spaced apart second masks to provide a plurality of pad masks after patterning the plurality of spaced apart first masks, pattern-

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ing the pad layer using the plurality of pad masks to form the plurality of spaced apart pads, and removing the pad masks after patterning the pad layer.

Forming the plurality of spaced apart second masks may precede forming the plurality of spaced apart first masks. In addition, patterning the pad layer may include patterning the plurality of spaced apart second masks using the plurality of spaced apart first masks, removing the plurality of spaced apart first masks to provide a plurality of pad masks after patterning the plurality of spaced apart second masks, patterning the pad layer using the plurality of pad masks to form the plurality of spaced apart pads, and removing the pad masks after patterning the pad layer.

The substrate may include a plurality of memory cell transistors, and each of the plurality of spaced apart pads may be electrically coupled to a source/drain region of a respective one of the memory cell transistors. After forming the plurality of pads, a plurality of memory cell capacitors may be formed wherein each of the memory cell capacitors is electrically coupled to a respective one of the pads.

The second direction may be perpendicular with respect to the first direction.

Forming the plurality of spaced apart second masks may include forming a third plurality of spaced apart patterns, and forming a fourth plurality of spaced apart patterns that are self-aligned with the third plurality of spaced apart patterns.

According to some other embodiments, an electronic device may include a substrate, and a plurality of spaced apart pads on the substrate. Each of the pads may include first, second, third, and fourth sides. The first and third sides may be opposite sides that are substantially straight, and the second and fourth sides may be opposite sides that are curved.

The plurality of pads may be arranged in linear columns in a direction that is parallel with the first and third sides, and a center line connecting centers of adjacent pads of different columns may define an angle of at least 60 degrees and less than 90 degrees relative to the direction that is parallel with the first and third sides.

One of the second and fourth sides may be concave, and the other of the second and fourth sides may be convex.

Moreover, the plurality of pads may be arranged in linear columns, wherein pads of a first column may be arranged with the convex sides pointing in a first direction parallel to a direction of the columns, wherein pads of a second column may be arranged with the convex sides pointing in a second direction parallel to the direction of the columns, and wherein the first and second directions may be opposite directions.

The substrate may include a plurality of memory cell transistors, and each of the spaced apart pads may be electrically coupled to a source/drain region of a respective one of the memory cell transistors. In addition, each of a plurality of memory cell capacitors may be electrically coupled to a respective one of the pads.

According to still other embodiments, an electronic device may include a substrate, and a plurality of spaced apart pads on the substrate. Each of the pads may include first and second opposing sides wherein the first side is concave and the second side is convex.

Each of the pads may include third and fourth opposing sides extending between the first and second sides, and the third and fourth sides may be opposite sides that are substantially straight.

The plurality of pads may be arranged in linear columns in a direction that is parallel with the first and third sides, and

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a center line connecting centers of adjacent pads of different columns may define an angle of at least 60 degrees and less than 90 degrees relative to the direction that is parallel with the first and third sides.

The plurality of pads may be arranged in linear columns. Pads of a first column may be arranged with the convex sides pointing in a first direction parallel to a direction of the columns, pads of a second column may be arranged with the convex sides pointing in a second direction parallel to the direction of the columns, and the first and second directions may be opposite directions.

The substrate may include a plurality of memory cell transistors, and each of the spaced apart pads may be electrically coupled to a source/drain region of a respective one of the memory cell transistors. In addition, each of a plurality of memory cell capacitors may be electrically coupled to a respective one of the pads.

According to yet other embodiments, an electronic device may include a substrate, and a plurality of spaced apart pads on the substrate. The plurality of pads may be arranged in linear columns, and a center line connecting centers of adjacent pads of different columns may define an angle of at least 60 degrees and less than 90 degrees relative to a direction of the columns.

Each of the pads may include first, second, third, and fourth sides, the first and third sides may be opposite sides that are substantially straight, and the second and fourth sides may be opposite sides that are curved. Moreover, one of the second and fourth sides may be concave and the other of the second and fourth sides may be convex. Pads of a first column are arranged with the convex sides pointing in a first direction parallel to the direction of the columns, pads of a second column may be arranged with the convex sides pointing in a second direction parallel to the direction of the columns, and the first and second directions may be opposite directions.

The substrate may include a plurality of memory cell transistors, and each of the spaced apart pads may be electrically coupled to a source/drain region of a respective one of the memory cell transistors. Moreover, each of a plurality of memory cell capacitors may be electrically coupled to a respective one of the pads.

According to still more embodiments, a dynamic random access memory device may include a substrate having a plurality of memory cell transistors. Each of a plurality of spaced apart pads on the substrate may be electrically coupled to a source/drain region of a respective one of the memory cell transistors. The plurality of pads may be arranged in linear columns, and a center line connecting centers of adjacent pads of different columns may define an angle of at least 60 degrees and less than 90 degrees relative to a direction of the columns. Each of a plurality of memory cell capacitors may be electrically coupled to a respective one of the pads.

Each of the pads may include first, second, third, and fourth sides, the first and third sides may be opposite sides that are substantially straight, and the second and fourth sides may be opposite sides that are curved. One of the second and fourth sides may be concave, and the other of the second and fourth sides may be convex. Pads of a first column may be arranged with the convex sides pointing in a first direction parallel to the direction of the columns, pads of a second column may be arranged with the convex sides pointing in a second direction parallel to the direction of the columns, and the first and second directions may be opposite directions.

BRIEF DESCRIPTION OF THE DRAWINGS

Example embodiments will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings. FIGS. 1-49 represent non-limiting, example embodiments as described herein.

FIGS. 1, 4, 8, 13, 16, 18, 21 and 24 are plan views illustrating stages of forming pads in accordance with example embodiments, and FIGS. 2-3, 5-7, 9-12, 14-15, 17, 19-20 and 22-23 are related cross-sectional views illustrating stages of forming the pads in accordance with example embodiments;

FIG. 25 is a plan view illustrating a pad array in accordance with example embodiments;

FIG. 26 is a plan view illustrating a pad array in accordance with example embodiments;

FIG. 27 is a plan view illustrating a pad array in accordance with example embodiments;

FIGS. 28, 30, 32, 34, 36, 38, 40, 43 and 44 are related plan views illustrating stages of a method of manufacturing a semiconductor device in accordance with example embodiments, and FIGS. 29, 31, 33, 35, 37, 39, 41, 42, 45 and 46 are cross-sectional views illustrating stages of a method of manufacturing the semiconductor device in accordance with example embodiments;

FIG. 47 is a plan view illustrating the locations of second contact plugs, landing pads and lower electrodes in the semiconductor device of FIG. 46;

FIG. 48 is a plan view illustrating locations of second contact plugs, landing pads and lower electrodes in the semiconductor device in accordance with other example embodiments;

FIG. 49 is a cross-sectional view of the semiconductor device in FIG. 48; and

FIGS. 50 and 51 are cross-sectional views illustrating stages of a method of manufacturing a semiconductor device in accordance with example embodiments.

DETAILED DESCRIPTION

Example embodiments will now be described more fully with reference to the accompanying drawings, in which example embodiments are shown. Example embodiments may, however, be embodied in many different forms and should not be construed as limited to the example embodiments set forth herein. In the drawings, the thicknesses of layers and regions are exaggerated for clarity. Like reference numerals in the drawings denote like elements, and thus their repeated description may be omitted and/or abbreviated.

It will be understood that when an element or layer is referred to as being “on,” “connected to” or “coupled to” another element or layer, it can be directly on, connected or coupled to the other element or layer or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly connected to” or “directly coupled to” another element or layer, there are no intervening elements or layers present. Like numerals refer to like elements throughout. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items. Other words used to describe the relationship between elements or layers should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” “on” versus “directly on”).

It will be understood that, although the terms first, second, third, etc. may be used herein to describe various elements,

components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. Unless indicated otherwise, these terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

Spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the exemplary term “below” can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting of the example embodiments. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Example embodiments are described herein with reference to cross-sectional illustrations that are schematic illustrations of idealized example embodiments (and intermediate structures). As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, example embodiments should not be construed as limited to the particular shapes of regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, an implanted region illustrated as a rectangle will, typically, have rounded or curved features and/or a gradient of implant concentration at its edges rather than a binary change from implanted to non-implanted region. Likewise, a buried region formed by implantation may result in some implantation in the region between the buried region and the surface through which the implantation takes place. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to limit the scope of the present disclosure.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

FIGS. 1, 4, 8, 13, 16, 18, 21 and 24 are plan views illustrating stages of forming pads on substrate 99 in accordance with example embodiments, and FIGS. 2-3, 5-7, 9-12,

14-15, 17, 19-20 and **22-23** are related cross-sectional views illustrating stages of forming the pads in accordance with example embodiments.

Each of the cross-sectional views includes cross-sections of the corresponding plan view cut along lines A-A', B-B', C-C', D-D', E-E' and F-F', respectively. The lines A-A', B-B' and C-C' extend in a second direction substantially parallel to a top surface of an etching object layer, and the lines D-D', E-E' and F-F' extend in a first direction substantially parallel to the top surface of the etching object layer and substantially perpendicular to the second direction.

The method of forming the pads may be performed together with a method of forming wirings. That is, the pads may be formed in a first region I according to the method of forming the pads, and simultaneously the wirings may be formed in a second region II according to the method of forming the wirings. Thus, a portion of each cross-sectional view labeled II also illustrates a cross-section of the second region II cut along the second direction (not shown in FIG. 1 or in any of the other plan views).

Referring to FIGS. 1 and 2, a first layer **110**, a second layer **120**, a first mask layer **130**, a third layer **140** and a fourth layer **150** may be sequentially formed on an etching object layer **100** (also referred to as a pad layer), and first and third photoresist patterns **160** and **165** may be formed on the fourth layer **150** in the first and second regions I and II, respectively.

The etching object layer **100** may include various types of layers that may be patterned to be transformed into patterns, e.g., pads, wirings, masks, etc. Thus, the etching object layer **100** may be referred to as a pad layer, a wiring layer, a mask layer, etc., in accordance with the desired patterns. The etching object layer **100** may include a conductive material or an insulating material. Examples of the conductive material may include a metal, (e.g., tungsten, titanium, tantalum, etc.), a metal nitride, a metal silicide, a doped polysilicon, etc., and examples of the insulating material may include silicon nitride, silicon oxide, silicide oxynitride, etc.

For example, the first layer **110** may be an amorphous carbon layer (ACL), the second and fourth layers **120** and **150** may include an oxynitride, e.g., plasma enhanced silicon oxynitride (PE-SION), the first mask layer **130** may include an oxide, e.g., atomic layer deposition oxide (ALD-OX), and the third layer **140** may include spin-on-hardmask.

In example embodiments, the first photoresist pattern **160** may extend in the first direction, and a plurality of first photoresist patterns **160** may be formed in the second direction. Each of the first photoresist patterns **160** may extend in a non-linear pattern (also referred to as a waveform) along an axis in the first direction. That is, each first photoresist pattern **160** may not extend in a straight line in the first direction but may fluctuate right and left as it extends along an axis in the first direction, and thus may have an amplitude along the second direction. The third photoresist pattern **165** may entirely cover the second region II.

An anti-reflective coating (ARC) layer (not shown) may be further formed between the fourth layer **150** and the first photoresist pattern **160** and/or between the fourth layer **150** and the third photoresist pattern **165**.

Referring to FIG. 3, in the first region I, the fourth and third layers **150** and **140** may be sequentially etched using the first photoresist pattern **160** as an etching mask to form fourth and third layer patterns **152** and **142**, respectively, and a top surface of the first mask layer **130** may be exposed. In example embodiments, a plurality of third layer patterns **142** and a plurality of fourth layer patterns **152** may be formed

in the second direction. Hereinafter, one of the third layer patterns **142** and one of the fourth layer patterns **152** thereon may be referred to simply as a first pattern **142** and **152**. Each first pattern **142** and **152**, like the first photoresist pattern **160**, may extend in a waveform along the first direction, and a plurality of first patterns **142** and **152** may be formed in the second direction. In the second region II, the third photoresist pattern **165** entirely covers the fourth layer **150**, and thus the fourth layer **150** may not be etched in the second region II.

The first and third photoresist patterns **160** and **165** may be removed. In example embodiments, the first and third photoresist patterns **160** and **165** may be removed using an ashing process and/or a stripping process.

Referring to FIGS. 4 and 5, a second mask layer **170** may be formed on the plurality of first patterns **142** and **152** and the exposed top surface of the first mask layer **130** in the first region I, and on the fourth layer **150** in the second region II. A second pattern **180** may be formed on a portion of the second mask layer **170** between the plurality of first patterns **142** and **152**.

In example embodiments, the second mask layer **170** may be conformally formed on sidewalls and top surfaces of the first patterns **142** and **152**, on the exposed top surface of the first mask layer **130**, and on the fourth layer **150**. In example embodiments, the second mask layer **170** may be formed to include a material substantially the same as that of the first mask layer **130**, e.g., ALD-OX. Thus, the first and second mask layers **130** and **170** in the first region I may be merged into a layer, and the merged layer will be shown as a single layer in figures after FIG. 5.

In example embodiments, the second pattern **180** may be formed by forming a filling layer on the second mask layer **170** to sufficiently fill a space between the plurality of first patterns **142** and **152** and planarizing an upper portion of the filling layer. The filling layer may be formed to include a material substantially the same as that of the third layer **140**, and thus may include, e.g., SOH (spin-on-hardmask). The planarization process may be performed by an etch back process and/or a chemical mechanical polishing (CMP) process. The second pattern **180** may have a top surface substantially coplanar with or lower than an uppermost portion of the top surface of the second mask layer **170**.

The second mask layer **170** may be conformally formed on the sidewalls and the top surfaces of the first patterns **142** and **152**, the exposed top surface of the first mask layer **130** and the fourth layer **150**, and thus the second pattern **180** formed on the portion of the second mask layer **170** between the plurality of first patterns **142** and **152** in the first region I may have a shape substantially the same as or similar to that of each first pattern **142** and **152**. In an example embodiment, the second pattern **180** may be formed to have a width along the second direction substantially the same as that of each first pattern **142** and **152** along the second direction.

Referring to FIG. 6, the merged first and second mask layers **130** and **170** in the first region I and the second mask layer **170** in the second region II may be etched using the first patterns **142** and **152** and the second patterns **180** as an etching mask to form first masks **172** in the first region I and to remove the second mask layer **170** from the second region II. In the etching process, the fourth layer pattern **152** of the first pattern **142** and **152** may be removed from the first region I, and the fourth layer **150** may be removed from the second region II.

Thus, in the first region I, a plurality of first structures each of which may include the first mask **172** and the third

layer pattern **142** sequentially stacked on the second layer **120**, and a plurality of second structures each of which may include the first mask **172** and the second pattern **180** sequentially stacked on the second layer **120** may be formed. Each of the first structures and each of the second structures, like the first pattern **142** and **152** and the second pattern **180**, may extend in a non-linear pattern (also referred to as a waveform) along an axis in the first direction. In the second region II, the first mask layer **130** and the third layer **140** that are sequentially stacked on the second layer **120** may remain.

Referring to FIG. 7, the third layer patterns **142** and the second patterns **180** may be removed from the first region I to expose the first masks **172**, and the third layer **140** may be removed from the second region II to expose the first mask layer **130**. Each of the exposed first masks **172** in the first region I may extend in a non-linear pattern (also referred to as a waveform) along the first direction, and the exposed first mask layer **130** in the second region II may entirely cover the second layer **120**. In example embodiments, the third layer patterns **142**, the second patterns **180**, and the third layer **140** may be removed using an ashing process and/or a stripping process.

Referring to FIGS. 8 and 9, in the first region I, a first planarization layer **200** may be formed on the second layer **120** to sufficiently cover the first masks **172**, and in the second region II, the first planarization layer **200** may be formed on the first mask layer **130**. A fifth layer **210**, a third mask layer **220**, a sixth layer **230** and a seventh layer **240** may be sequentially formed on the first planarization layer **200** both in the first and second regions I and II. Second and fourth photoresist patterns **250** and **255** may be formed on the seventh layer **240** in the first and second regions I and II, respectively.

The first planarization layer **200** may be formed to include a material substantially the same as that of the third layer **140**, and thus may include, e.g., SOH. The fifth and seventh layers **210** and **240** may be formed to include a material substantially the same as that of the second and fourth layers **120** and **150**, and thus may include an oxynitride, e.g., PE-SiON. The third mask layer **220** may be formed to include a material substantially the same as that of the first and second mask layers **130** and **170**, and thus may include an oxide, e.g., ALD-OX. The sixth layer **230** may be formed to include a material substantially the same as that of the third layer **140** and the first planarization layer **200**, and thus may include, e.g., SOH.

In example embodiments, the second photoresist pattern **250** may extend in the second direction, and a plurality of second photoresist patterns **250** may be formed in the first direction. Each of the second photoresist patterns **250** may extend in a straight line in the second direction. In example embodiments, the second photoresist patterns **250** may be spaced apart from each other in the first direction at a distance of about 2 times to about 4 times of a width of each second photoresist pattern **250** in the first direction. The fourth photoresist pattern **255** may have various shapes according to the desired shape of the wirings, and e.g., may extend in the first direction.

An ARC layer (not shown) may be further formed between the seventh layer **240** and the second photoresist pattern **250** and/or between the seventh layer **240** and the fourth photoresist pattern **255**.

Referring to FIG. 10, a process substantially the same as or similar to that discussed with reference to FIG. 3 may be performed.

Thus, in the first region I, the seventh and sixth layers **240** and **230** may be sequentially etched using the second photoresist pattern **250** as an etching mask to form seventh and sixth layer patterns **242** and **232**, respectively, and a top surface of the third mask layer **220** may be exposed. In example embodiments, a plurality of sixth layer patterns **232** and a plurality of seventh layer patterns **242** may be formed in the first direction. Hereinafter, one of the sixth layer patterns **232** and one of the seventh layer patterns **242** thereon may be referred to simply as a third pattern **232** and **242**. Each third pattern **232** and **242**, like the second photoresist pattern **250**, may extend in a straight line in the second direction, and a plurality of third patterns **232** and **242** may be formed in the first direction.

In the second region II, the seventh and sixth layers **240** and **230** may be sequentially etched using the fourth photoresist pattern **255** as an etching mask to form ninth and eighth layer patterns **243** and **233**, respectively, and a top surface of the third mask layer **220** may be exposed. Hereinafter, the eighth and ninth layer patterns **233** and **243** may be referred to simply as a fifth pattern **233** and **243**.

The second and fourth photoresist patterns **250** and **255** may be removed.

Referring to FIG. 11, a process substantially the same as or similar to that illustrated with reference to FIGS. 4 and 5 may be performed.

Thus, in the first region I, a fourth mask layer **260** may be formed on the plurality of third patterns **232** and **242** and the exposed top surface of the third mask layer **220**, and a fourth pattern **270** may be formed on a portion of the fourth mask layer **260** between the plurality of third patterns **232** and **242**. In the second region II, the fourth mask layer **260** may be formed on the plurality of fifth patterns **233** and **243** and the exposed top surface of the third mask layer **220**, and the fourth pattern **270** may be formed on a portion of the fourth mask layer **260** between the plurality of fifth patterns **233** and **243**.

In example embodiments, the fourth mask layer **260** may be conformally formed on sidewalls and top surfaces of the third patterns **232** and **242**, sidewalls and top surfaces of the fifth patterns **233** and **243**, and the exposed top surface of the third mask layer **220**. In example embodiments, the fourth mask layer **260** may be formed to include a material substantially the same as that of the third mask layer **220**, e.g., ALD-OX. Thus, the third and fourth mask layers **220** and **260** may be merged into a layer, and the merged layer will be shown as a single layer in figures after FIG. 12.

The fourth pattern **270** may be formed to include a material substantially the same as that of the sixth and eighth layer patterns **232** and **233**, and thus may include, e.g., SOH. The fourth pattern **270** may have a top surface substantially coplanar with or lower than an uppermost portion of the top surface of the fourth mask layer **260**. The fourth pattern **270** may have a shape substantially the same as or similar to that of each third pattern **232** and **242** in the first region I, and may have a shape substantially the same as or similar to that of each fifth pattern **233** and **243** in the second region II. In an example embodiment, the fourth pattern **270** may be formed to have a width along the first direction substantially the same as that of each third pattern **232** and **242** along the first direction in the first region I.

Referring to FIG. 12, a portion of the fourth pattern **270** formed in the second region II may be removed. In example embodiments, after forming a mask (not shown) covering the first region I, an ashing process and/or a stripping process may be performed to remove the portion of the fourth pattern **270** in the second region II.

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Referring to FIGS. 13 and 14, a process substantially the same as or similar to that illustrated with reference to FIG. 6 may be performed.

Thus, in the first region I, the merged third and fourth mask layers 220 and 260 may be etched using the third patterns 232 and 242 and the fourth patterns 270 as an etching mask to form second masks 262. In the etching process, the seventh layer pattern 242 of the third pattern 232 and 242 may be removed from the first region I. In the second region II, the merged third and fourth mask layers 220 and 260 may be etched using the fifth patterns 233 and 243 as an etching mask to form fourth masks 263. In the etching process, the ninth layer pattern 243 of the fifth pattern 233 and 243 may be removed from the second region II.

Thus, in the first region I, a plurality of third structures (each of which may include the second mask 262 and the sixth layer pattern 232 sequentially stacked on the fifth layer 210), and a plurality of fourth structures (each of which may include the second mask 262 and the fourth pattern 270 sequentially stacked on the fifth layer 210) may be formed. Each of the third structures and each of the fourth structures, like the third pattern 232 and 242 and the fourth pattern 270, may extend in a straight line in the second direction. In the second region II, a plurality of fifth structures (each of which may include the fourth mask 263 and the eighth layer pattern 233 sequentially stacked on the fifth layer 210) may be formed. Each of the fifth structures may have a shape substantially the same as that of each fifth pattern 233 and 243.

Referring to FIG. 15, a process substantially the same as or similar to that illustrated with reference to FIG. 7 may be performed.

Thus, the sixth layer patterns 232 and the fourth patterns 270 may be removed from the first region I to expose the second masks 262, and the eighth layer patterns 233 may be removed from the second region II to expose the fourth masks 263. Each of the exposed second masks 262 may extend in a straight line in the second direction.

Referring to FIGS. 16 and 17, the fifth layer 210 and the first planarization layer 200 may be etched using the second masks 262 in the first region I and the fourth masks 263 in the second region II as an etching mask to form a fifth layer pattern 212 and a first planarization layer pattern 202 in the first region I and a tenth layer pattern 213 and a second planarization layer pattern 203 in the second region II. Thus, portions of the first masks 172 and the second layer 120 may be exposed in the first region I, and a portion of the first mask layer 130 may be exposed in the second region II.

Referring to FIGS. 18 and 19, in the first region I, the second masks 262 and the exposed portion of the first masks 172 may be removed to form a plurality of third masks 174. That is, as the exposed portion of the first masks 172 is removed, each first mask 172 extending in the first direction may be divided into the plurality of third masks 174. Accordingly, the third masks 174 may be formed both in the first and second directions. In the etching process, the fifth layer pattern 212 may also be removed.

In the second region II, the fourth masks 263 and the exposed portion of the first mask layer 130 may be removed to form a plurality of fifth masks 133. In the etching process, the tenth layer pattern 213 may be also removed.

Referring to FIG. 20, a second planarization layer 280 may be formed on the second layer 120 to sufficiently cover the first and second planarization layer patterns 202 and 203 and the third and fifth masks 174 and 133, and an upper portion of the second planarization layer 280 may be planarized.

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In example embodiments, the second planarization layer 280 may be formed to include a material substantially the same as that of the first and second planarization layer patterns 202 and 203, e.g., SOH. Thus, the first and second planarization layer patterns 202 and 203 may be merged into the second planarization layer 280, and only the merged second planarization layer 280 is shown in FIG. 20.

An eleventh layer 290 may be formed on the second planarization layer 280, and a fifth photoresist pattern 295 may be formed thereon in the second region II.

The eleventh layer 290 may be formed to include an oxynitride, e.g., PE-SiON. In example embodiments, the fifth photoresist pattern 295 may overlap a portion of the sixth mask 133 when viewed from a top side, i.e., the fifth photoresist pattern 295 may vertically overlap the portion of the sixth mask 133.

Referring to FIGS. 21 and 22, the eleventh layer 290 and the second planarization layer 280 may be patterned using the fifth photoresist pattern 295 as an etching mask so that the third masks 174 and a portion of the second layer 120 may be exposed in the first region I and an eleventh layer pattern 293 and a third planarization layer pattern 283 may be formed in the second region II. Additionally, the sixth masks 133 and a portion of the second layer 120 may be exposed, however, the portion of the sixth mask 133 overlapped with the fifth photoresist pattern 295 may not be exposed but covered by the third planarization layer pattern 283.

Referring to FIG. 23, after removing the fifth photoresist pattern 295 and the eleventh layer pattern 293, the second layer 120 and the first layer 110 may be patterned using the third masks 174, the sixth masks 133, and the third planarization layer pattern 283 as an etching mask so that a second layer pattern 122 and a first layer pattern 112 may be formed and a portion of the etching object layer 100 may be exposed in the first region I, and a thirteenth layer pattern 123 and a twelfth layer pattern 113 may be formed and a portion of the etching object layer 100 may be exposed in the second region II.

Referring to FIGS. 23 and 24, the third masks 174 and the second layer pattern 122 in the first region I, and the sixth masks 133, the third planarization layer pattern 283, and the thirteenth layer pattern 123 in the second region II may be removed. The exposed portion of the etching object layer 100 in the first region I may be etched using the first layer pattern 112 as an etching mask to form a plurality of pads 102, and the exposed portion of the etching object layer 100 in the second region II may be etched using the twelfth layer pattern 113 as an etching mask to form a plurality of wirings (not shown).

As illustrated above, the pads 102 may be formed by a double patterning technology (DPT) process using the first photoresist pattern 160 extending in a non-linear pattern (also referred to as a waveform) along an axis in the first direction, and by a DPT process using the second photoresist pattern 250 extending in a straight line in the second direction. That is, when the pads 102 and the wirings are not simultaneously formed but only the pads 102 are formed in the first region I, the pads 102 may be formed by performing a DPT process only twice. In a method of forming the pads 102, portions of the etching object layer 100 that are commonly covered by the first mask structure including the first photoresist patterns 160 and the second pattern 180, and the second mask structure including the second photoresist patterns 250 and the fourth pattern 270 may remain to be

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transformed into the pads **102**. An array of the pads **102** (i.e., a pad array) will be discussed in greater detail below with reference to FIG. **25**.

When the pads **102** and the wirings are simultaneously formed in the first and second regions I and II, respectively, the pads **102** and the wirings may be formed by performing an etching process three times, which may include performing a DPT process twice. When the wirings are formed in the second region II, not only a portion of the etching object layer **100** commonly covered by the fifth photoresist pattern **295** and the sixth mask **133** but also a portion thereof covered only by one of the fifth photoresist pattern **295** and the sixth mask **133** may remain, so that a portion of the etching object layer **100** covered by any one of the fifth photoresist pattern **295** and the sixth mask **133** may be transformed into the wirings.

According to the shape of the fifth photoresist pattern **295**, the wirings may thus be formed by other methods that are different from the above method. For example, after forming a preliminary mask using a photoresist pattern having a size large enough to cover several adjacent patterns of a desired wiring, the preliminary mask may be divided into a plurality of masks using a photoresist pattern covering only a portion of the preliminary mask as an etching mask, and finally the etching object layer **100** may be patterned using the mask as an etching mask to form the desired wiring.

The method of forming the pads **102** and the wirings may be used to manufacture a semiconductor device including a cell region and a peripheral circuit region. That is, the method of forming the pads **102** in the first region I may be used (e.g., to form capacitor landing pads in the cell region), and the method of forming the wirings in the second region II may be used, (e.g., to form bit lines in the peripheral circuit region).

FIG. **25** is a plan view illustrating a pad array in accordance with example embodiments.

Referring to FIG. **25**, the pad array may include a first pad column **11** and a second pad column **13**. In example embodiments, a plurality of first pad columns **11** may be formed in the first direction, and also a plurality of second pad columns **13** may be formed in the first direction. The first and second pad columns **11** and **13** may be arranged alternately and repeatedly in the first direction. That is, the pad array may have a structure in which a first pad column **11**, a second pad column **13**, a first pad column **11**, and a second pad column **13** are arranged in this order. Thus, each second pad column **13** may be interposed between the adjacent first pad columns **11**. In example embodiments, adjacent first and second pad columns **11** and **13** may be disposed at a given distance from each other in the first direction.

Each first pad column **11** may have a plurality of first pads **12** disposed in the second direction substantially perpendicular to the first direction, and each second pad column **13** may have a plurality of second pads **14** disposed in the second direction. In example embodiments, in each first pad column **11**, the first pads **12** may be disposed at a given distance from each other in the second direction, and in each second pad column **13**, the second pads **14** may be disposed at a given distance from each other in the second direction.

Each first pad **12** may have four sides, and first and second sides **a1** and **a2** of the four sides that are opposite to each other may be substantially straight lines, each of which may be parallel to the second direction. The other two opposite sides of the four sides (i.e., third and fourth sides **b1** and **b2**) may be curved (with side **b1** being concave and with side **b2** being convex) in the second direction. Particularly, the third side **b1** of each first pad **12** may include two straight lines,

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which may form a first angle α therebetween, and the fourth side **b2** of each first pad **12** may include two straight lines that are parallel to the respective two lines of the third side **b1**. In example embodiments, the first angle α may be an obtuse angle.

First and second pads **12** and **14** adjacent to each other in the first direction may form point symmetry with respect to a point located therebetween. Thus, each second pad **14** may also have four sides, and first and second sides **c1** and **c2** of the four sides that are opposite to each other may be substantially straight lines each of which may be parallel to the second direction. Additionally, the other two opposite sides of the four sides (i.e., third and fourth sides **d1** and **d2**) may be curved (with side **d2** being concave and with side **d1** being convex) in the second direction. Particularly, the third side **d1** of each second pad **14** may include two straight lines, which may form a second angle β therebetween, and the fourth side **d2** of each second pad **14** may include two straight lines that are parallel to the respective two lines of the third side **d1**. In example embodiments, the second angle β may be an obtuse angle, which may be substantially the same as the first angle α .

According to the shapes of the first and second pads **12** and **14**, the first and second pads **12** and **14** may be arranged in a pattern or waveform along an axis in the first direction. That is, the first and second pads **12** and **14** may be disposed in a zigzag fashion along the first direction.

An imaginary central line (CL) connecting centers of the first and second pads **12** and **14** adjacent to each other in the first direction may form an acute angle with the first direction or may be parallel with the first direction.

The counterclockwise direction may be considered as a positive angular direction. If a portion of the central line CL connecting a center of the first pad **12** to a center of the second pad **14** in this order forms a third angle A with the first direction, the third angle A may be a positive value. Additionally, if a portion of the central line CL connecting a center of the second pad **14** to a center of the first pad **12** in this order may form a fourth angle B with the first direction, the fourth angle B may be a negative value.

Alternatively, if the angular direction is not considered, i.e., if only the absolute value of the angle is considered, the third angle A or the fourth angle B may be in a range of about 0 to about 90 degrees. In example embodiments, the third and fourth angles A and B may be in a range of about 0 to about 30 degrees. When the third and fourth angles A and B are 30 degrees, the centers of the first and second pads **12** and **14** may form a honeycomb structure, that is, the centers of the first and second pads **12** and **14** may be disposed at vertices and centers of hexagons. Thus, in accordance with example embodiments, the first and second pads **12** and **14** may be arranged not only in a honeycomb structure but also in other structures.

FIG. **26** is a plan view illustrating a pad array in accordance with example embodiments.

Referring to FIG. **26**, the pad array may include a plurality of third pads **20** arranged both in the first and second directions substantially perpendicular to each other. Unlike the first and second pads **12** and **14** illustrated with reference to FIG. **25**, each third pad **20** may have first and second sides **e1** and **e2** substantially parallel to the second direction, and third and fourth sides **f1** and **f2** substantially parallel to the first direction. That is, unlike the first and second pads **12** and **14**, the third and fourth sides **f1** and **f2** of each third pad **20** may be neither concave nor convex but flat/straight in the second direction, and thus each third pad **20** may have a rectangular shape.

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The pad array may be formed using a sixth photoresist pattern (not shown) extending in a straight line along the first direction that is different from the first photoresist pattern 160 extending in a pattern/waveform along the first direction in FIG. 1.

According to present inventive concepts, the first mask structure includes the first photoresist patterns 160 extending in a non-linear pattern (also referred to as a waveform) along an axis in the first direction and the second pattern 180 between the first photoresist patterns 160 formed by a DPT process, and the second mask structure includes the second photoresist patterns 250 extending in a straight line in the second direction and the fourth pattern 270 between the second photoresist patterns 250 formed by a DPT process. Together, the first and second mask structures may serve as an etching mask for forming the etching object layer 100 so that only portions of the etching object layer 100 covered by both of the first and second mask structures may remain to serve as pads 12 and 14 and the pad array may be defined. The arrangement of the pads 12 and 14 may be changed by controlling a degree of fluctuation of the first photoresist pattern 160 toward the second direction, i.e., the amplitude, while it extends in the first direction, and this may correspond to the first and second angles α and β of the first and second pads 12 and 14, respectively, or the third and fourth angles A and B between the central line CL and the first direction.

That is, as the amplitude of the first photoresist pattern 160 toward the second direction decreases, the first and second angles α and β may increase, and the third and fourth angles A and B may decrease. Thus, when the first photoresist pattern 160 does not fluctuate substantially toward the second direction, i.e., when the sixth photoresist pattern is used, the third pads 20 may not be arranged in a zigzag fashion but linearly in the first direction, and each third pad 20 may have a rectangular shape. In this case, the first and second angles α and β or the third and fourth angles A and B may be substantially zero.

FIG. 27 is a plan view illustrating a pad array in accordance with example embodiments.

Referring to FIG. 27, the pad array may include a fourth pad column 15 and a fifth pad column 17. In example embodiments, a plurality of fourth pad columns 15 may be formed in the first direction, and also a plurality of fifth pad columns 17 may be formed in the first direction. The fourth and fifth pad columns 15 and 17 may be arranged alternately and repeatedly in the first direction, and may be disposed at a given distance from each other in the first direction.

Each fourth pad column 15 may have a plurality of fourth pads 16 disposed in the second direction substantially perpendicular to the first direction, and each fifth pad column 17 may have a plurality of fifth pads 18 disposed in the second direction. In example embodiments, in each fourth pad column 15, the fourth pads 16 may be disposed at a given distance from each other in the second direction, and in each fifth pad column 17, the fifth pads 18 may be disposed at a given distance from each other in the second direction.

Each fourth pad 16 may have four sides, and first and second sides g1 and g2 of the four sides that are opposite to each other may be substantially straight lines each of which may be parallel to the second direction. The other two opposite sides of the four sides, i.e., third and fourth sides h1 and h2 may be parallel curves that are respectively concave and convex in the second direction.

Fourth and fifth pads 16 and 18 adjacent to each other in the first direction may form point symmetry with respect to a point located therebetween. Thus, each fifth pad 18 may

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also have four sides, and first and second sides i1 and i2 of the four sides that are opposite to each other may be substantially straight lines each of which may be parallel to the second direction. Additionally, the other two opposite sides of the four sides, i.e., third and fourth sides j1 and j2 may be parallel curves that are respectively convex and concave in the second direction.

According to the shapes of the fourth and fifth pads 16 and 18, the fourth and fifth pads 16 and 18 may be arranged in a waveform along the first direction. That is, the fourth and fifth pads 16 and 18 may be disposed in a zigzag fashion along the first direction. However, unlike the first and second pads 12 and 14 in FIG. 25, each of the third and fourth sides h1, h2, j1 and j2 of the fourth and fifth pads 16 and 18 in FIG. 27 may not be two straight lines but may be curved (also referred to as bent).

The pad array may be formed using a seventh photoresist pattern (not shown) extending in a curve along the first direction that is different from the first photoresist pattern 160 in FIG. 1.

FIGS. 28, 30, 32, 34, 36, 38, 40, 43 and 44 are plan views illustrating stages of a method of manufacturing a semiconductor device in accordance with example embodiments, and FIGS. 29, 31, 33, 35, 37, 39, 41, 42, 45 and 46 are cross-sectional views illustrating stages of a method of manufacturing the semiconductor device in accordance with example embodiments. Each of the cross-sectional views includes cross-sections of the corresponding plan view cut along lines G-G', H-H', K-K' and L-L', respectively. The lines G-G' and H-H' extend in a second direction substantially parallel to a top surface of a substrate, and the lines K-K' and L-L' extend in a first direction substantially parallel to the top surface of the substrate and substantially perpendicular to the second direction.

In this method, the method of forming the pads in the first region illustrated with reference to FIGS. 1 to 27 may be applied to forming capacitor landing pads in a cell region of a dynamic random access memory (DRAM) device. The method of forming the wirings in the second region performed together with the method of forming the pads in the first region may be applied to forming various patterns in a peripheral circuit region of the DRAM device (e.g., bit lines), however, other such patterns are not illustrated herein. Hereinafter, only the method of manufacturing the cell region of the DRAM device will be illustrated.

Referring to FIGS. 28 and 29, a first hard mask 310 may be formed on a substrate 300, and an upper portion of the substrate 300 may be etched using the first hard mask 310 as an etching mask to form a first trench 305. For example, the substrate 300 may be a silicon substrate, a germanium substrate, a silicon-germanium substrate, a silicon-on-insulator (SOI) substrate, a germanium-on-insulator (GOI) substrate, etc. The first hard mask 310 may be formed to include a nitride, e.g., silicon nitride.

An isolation layer may be formed on the substrate 300 to sufficiently fill the first trench 305, and an upper portion of the isolation layer may be planarized until a top surface of the substrate 300 is exposed to form an isolation layer pattern 320 in the first trench 305. The isolation layer may be formed to include an oxide, e.g., silicon oxide.

A region of the substrate 300 on which the isolation layer pattern 320 is formed may be defined as a field region, and a region of the substrate 300 on which no isolation layer pattern is formed may be defined as an active region. In example embodiments, a plurality of active regions may be formed, and each active region may extend in a third direction that is substantially parallel to the top surface of the

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substrate **300**, but that is neither parallel nor perpendicular to the first and second directions.

Impurities may be implanted into upper portions of the substrate **300** to form impurity regions (not shown). The impurity regions may form a transistor together with a first gate structure **360** (refer to FIG. **31**) subsequently formed, and may serve as source/drain regions of the transistor.

Referring to FIGS. **30** and **31**, the first hard mask **310**, the substrate **300** and the isolation layer pattern **320** may be partially removed to form second trenches each of which may extend in the second direction. The second trenches may be formed to have different depths at the substrate **300** and the isolation layer pattern **320** according to the etching selectivity therebetween. In example embodiments, two second trenches may be formed in each active region of the substrate **300**.

A first gate insulation layer **330** may be formed on upper surfaces of the substrate **300** exposed by the second trenches, and a first gate electrode **340** and a capping layer pattern **350** may be sequentially formed in each second trench. The first gate electrode **340** may fill a lower portion of each second trench and the capping layer pattern **350** may fill an upper portion of each second trench.

In example embodiments, the first gate insulation layer **330** may be formed using a thermal oxidation process or a chemical vapor deposition (CVD) process, and thus may be formed to include an oxide, e.g., silicon oxide.

The first gate electrode **340** may be formed by forming a first gate electrode layer on the first gate insulation layer **330**, the first hard mask **310** and the isolation layer pattern **320** to sufficiently fill the second trenches, and removing an upper portion of the first gate electrode layer through an etch back process and/or a CMP (chemical mechanical polishing) process. The first gate electrode layer may be formed to include a metal, e.g., tungsten, titanium, tantalum, etc., or a metal nitride, e.g., tungsten nitride, titanium nitride, tantalum nitride, etc.

The capping layer pattern **350** may be formed by forming a capping layer on the first gate electrode **340**, the first gate insulation layer **330**, the first hard mask **310** and the isolation layer pattern **320** to sufficiently fill remaining portions of the second trenches, and planarizing an upper portion of the capping layer until top surfaces of the first hard mask **310** and the isolation layer pattern **320** may be exposed. The capping layer may be formed to include a nitride, e.g., silicon nitride.

By the above process, the first gate structure **360** including the first gate insulation layer **330**, the first gate electrode **340** and the capping layer pattern **350** may be formed in each second trench. In example embodiments, the first gate structure **360** may extend in the second direction.

Referring to FIGS. **32** and **33**, a first insulating interlayer **370** may be formed on the first hard mask **310**, the isolation layer pattern **320** and the capping layer pattern **350**, and the first insulating interlayer **370** and the first hard mask **310** may be partially removed to form first contact holes **375** exposing the active regions of the substrate **300**, respectively. In example embodiments, each first contact hole **375** may expose a central top surface of each active region. When the first contact holes **375** are formed, the capping layer pattern **350** and the isolation layer pattern **320** may also be partially removed.

A first spacer **380** may be formed on a sidewall of each first contact hole **375**. The first spacers **380** may be formed by forming a first spacer layer on the sidewalls of the first contact holes **375**, the exposed top surface of the active regions, and the first insulating interlayer **370**, and aniso-

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tropically etching the first spacer layer. The first spacer layer may be formed to include a nitride, e.g., silicon nitride.

Referring to FIGS. **34** and **35**, a first contact plug **412** filling a remaining portion of each first contact hole **375** may be formed on the exposed top surface of the active region and the first spacer **380**. The first contact plug **412** may include a first metal layer pattern **402** and a barrier layer pattern **392** surrounding the first metal layer pattern **402**.

The first contact plugs **412** may be formed by forming a barrier layer on the exposed top surface of the active regions, the first spacers **380** and the first insulating interlayer **370**, by forming a first metal layer to sufficiently fill remaining portions of the first contact holes **375**, and by planarizing upper portions of the barrier layer and the first metal layer until a top surface of the first insulating interlayer **370** is exposed. The barrier layer may be formed to include a metal nitride (e.g., tungsten nitride, titanium nitride, tantalum nitride, etc.), and the first metal layer may be formed to include a metal (e.g., tungsten, aluminum, copper, etc.). Alternatively, the first contact plugs **412** may be formed to include doped polysilicon.

Referring to FIGS. **36** and **37**, a first bit line **422** and a second hard mask **432** may be sequentially formed on the first insulating interlayer **370** to contact the first plugs **412**.

The first bit line **422** and the second hard mask **432** may be formed by sequentially forming a second metal layer and a second hard mask layer on the first insulating interlayer **370**, the first contact plugs **412**, and the first spacers **380**, and by patterning the second hard mask layer and the second metal layer using a photolithography process. In example embodiments, each of the first bit line **422** and the second hard mask **432** may extend in the first direction, and a plurality of first bit lines **422** and a plurality of second hard masks **432** may be formed in the second direction. The second metal layer may be formed to include a metal, e.g., tungsten, aluminum, copper, etc., and the second hard mask layer may be formed to include a nitride, e.g., silicon nitride.

Referring to FIGS. **38** and **39**, a second spacer **442** may be formed on sidewalls of each first bit line **422** and each second hard mask **432**.

The second spacers **442** may be formed by forming a second spacer layer on the first bit lines **422**, the second hard masks **432**, the first contact plugs **412** and the first insulating interlayer **370**, and by anisotropically etching the second spacer layer. The second spacer layer may be formed to include a nitride, e.g., silicon nitride. In example embodiments, the second spacer **442** may extend in the first direction, and a plurality of second spacers **442** may be formed in the second direction.

The bit line **422**, the second hard mask **432** and the second spacer **442** may define a first bit line structure.

Referring to FIGS. **40** and **41**, a second insulating interlayer **450** may be formed on the first insulating interlayer **370** to cover the first bit line structures, and the second insulating interlayer **450**, the first insulating interlayer **370** and the first hard mask **310** may be partially etched to form second contact holes **455** exposing top surfaces of the active regions, respectively. When the second contact holes **455** are formed, the isolation layer pattern **320** may be partially etched. In example embodiments, a plurality of second contact holes **455** may be formed in the first direction between the first bit line structures. In example embodiments, the second contact holes **455** may be formed to be self-aligned with the first bit line structures, and two second contact holes **455** may be formed on each active region.

A second contact plug **462** filling a lower portion of each second contact hole **455** may be formed. The second contact

plugs 462 may be formed by forming a first conductive layer on the exposed top surfaces of the active regions, the first bit line structures, and the second insulating interlayer 450 to sufficiently fill the second contact holes 455, and by removing an upper portion of the first conductive layer. The first conductive layer may be formed to include, e.g., doped polysilicon.

Metal silicide patterns (not shown) may be further formed on top surfaces of the second contact plugs 462, thereby reducing a resistance between the second contact plugs 462 and landing pads 472 (refer to FIGS. 44 and 45) subsequently formed.

Referring to FIG. 42, a second conductive layer 470 may be formed on the second contact plugs 462, the first bit line structures and the second insulating interlayer 450 to sufficiently fill remaining portions of the second contact holes 455. The second conductive layer 470 may be formed to include a metal, e.g., tungsten, aluminum, copper, etc.

Alternatively, after a third conductive layer (not shown) is formed on the second contact plugs 462, the first bit line structures, and the second insulating interlayer 450 to sufficiently fill remaining portions of the second contact holes 455, an upper portion of the third conductive layer may be planarized until top surfaces of the first bit line structures and the second insulating interlayer 450 may be exposed to form contact plugs (not shown), and a fourth conductive layer (not shown) serving as a pad layer may be formed on the contact plugs, the first bit line structures and the second insulating interlayer 450. Hereinafter, only the case in which the second conductive layer 470 (serving as both of the contact plug and the pad layer) is formed will be illustrated.

Referring to FIG. 43, processes substantially the same as or similar to those illustrated with reference to FIGS. 1 to 23 may be performed. That is, a DPT process using the first photoresist pattern 160 extending in a waveform along the first direction and a DPT process using the second photoresist pattern 250 extending in a straight line in the second direction may be sequentially performed to pattern an upper portion of the second conductive layer 470.

Thus, referring to FIGS. 44 and 45, the landing pads 472 (each of which may include an upper portion having the shape of the pads 102 in FIG. 24) may be formed. A lower portion of each landing pad 472 may contact a top surface of each second contact plug 462.

Referring to FIG. 46, capacitors 530 contacting the landing pads 472, respectively, may be formed to complete the semiconductor device.

That is, a third insulating interlayer 480 may be formed on the first bit line structures and the second insulating interlayer 450 to cover the landing pads 472, an upper portion of the third insulating interlayer 480 may be planarized until a top surface of the landing pads 472 may be exposed. An etch stop layer 490 and a mold layer (not shown) may be sequentially formed on the third insulating interlayer 480 and the landing pads 472, and may be partially etched to form third contact holes (not shown) exposing top surfaces of the landing pads 472, respectively. In the etching process, a top surface of the third insulating interlayer 480 may also be partially exposed. In example embodiments, the third contact holes may form a honeycomb structure. That is, the third contact holes may be formed at positions corresponding to vertices and centers of hexagons when viewed from a top side.

After a lower electrode layer is formed on sidewalls of the third contact holes, the exposed top surfaces of the landing pads 472, the exposed top surface of the third insulating interlayer 480, and the mold layer, a sacrificial layer (not

shown) may be formed on the lower electrode layer to sufficiently fill remaining portions of the third contact holes, and upper portions of the sacrificial layer and the lower electrode layer may be planarized until a top surface of the mold layer is exposed to divide the lower electrode layer into a plurality of pieces. The sacrificial layer and the mold layer may be removed. Thus, a plurality of cylindrical lower electrodes 500 may be formed on the sidewalls of the third contact holes, the exposed top surfaces of the landing pads 472, and the exposed top surface of the third insulating interlayer 480, and the lower electrodes 500 may form a honeycomb structure in accordance with the honeycomb structure of the third contact holes. Alternatively, a plurality of pillar-shaped lower electrodes may be formed instead of the plurality of cylindrical lower electrodes 500, and in this case, the lower electrode layer may entirely fill the third contact holes and the sacrificial layer may not be formed. Hereinafter, only the case in which the cylindrical lower electrodes 500 are formed will be illustrated.

A dielectric layer 510 may be formed on the lower electrodes 500 and the etch stop layer 490, and an upper electrode 520 may be formed on the dielectric layer 510 to form the capacitors 530, each of which may include the lower electrode 500, the dielectric layer 510, and the upper electrode 520. The lower and upper electrodes 500 and 520 may be formed to include doped polysilicon, a metal, a metal nitride, etc., and the dielectric layer 510 may be formed to include a metal oxide, silicon oxide, etc.

FIG. 47 is a plan view illustrating locations of the second contact plugs 462, the landing pads 472, and the lower electrodes 500 in the semiconductor device of FIG. 46. In FIG. 47, only shapes of the upper portions of the landing pads 472 are shown.

Referring to FIG. 47, the second contact plugs 462 may be arranged at a given distance from each other in the first direction between the second spacers 442 of the first bit line structures, and the landing pads 472 may be formed to contact top surfaces of the second contact plugs 462, respectively. The landing pads 472 may be disposed in the first direction in a waveform that may fluctuate toward the second direction. That is, the landing pads 472 may be disposed in a zigzag fashion in the first direction. Thus, when viewed from a top side, a second center C2 of each landing pad 472 may not be coincident with a first center C1 of the corresponding second contact plug 462, and may be spaced apart from the first center C1 by a first distance D1.

The lower electrodes 500 may be arranged in a honeycomb structure in consideration of making best use of space and avoiding mutual interference therebetween. That is, the lower electrodes 500 may be arranged at positions corresponding to vertices and centers of hexagons when viewed from a top side. Thus, the positions of the lower electrodes 500 may be different from those of the second contact plugs 462 when viewed from a top side. In order to electrically connect the second contact plugs 462 with the lower electrodes 500, the landing pads 472 may be formed therebetween. In example embodiments, the second center C2 of each landing pad 472 may be located between the first center C1 of each second contact plug 462 and a third center C3 of each lower electrode 500, when viewed from a top side.

If the landing pads 472 are formed in a honeycomb structure like the lower electrodes 500, and thus the second center C2 of each landing pad 472 may be coincident with the third center C3 of the corresponding lower electrode 500, resistance between the landing pads 472 and the second contact plugs 462 may be high due to the small contact area therebetween. However, in accordance with example

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embodiments, the second center C2 of each landing pad 472 may be located between the first center C1 of each second contact plug 462 and the third center C3 of each lower electrode 500, and thus resistance between the landing pads 472 and the second contact plugs 462 may be reduced.

If the landing pads 472 are formed such that the second center C2 of each landing pad 472 may be coincident with the first center C1 of the corresponding second contact plug 462, the resistance between the landing pads 472 and the lower electrodes 500 may be relatively high due to the small contact area therebetween. However, in accordance with example embodiments, second center C2 of each landing pad 472 may be located between the first center C1 of each second contact plug 462 and the third center C3 of each lower electrode 500, and thus resistance between the landing pads 472 and the lower electrodes 500 may be reduced.

That is, according to the first distance D1 between the second center C2 of each landing pad 472 and the first center C1 of each second contact plug 462, and a second distance D2 between the second center C2 of each landing pad 472 and the third center C3 of each lower electrode 500, resistance between the landing pads 472 and the second contact plugs 462 and resistance between the landing pads 472 and the lower electrodes 500 may be changed. In example embodiments, the locations of the landing pads 472 may be controlled by changing the fluctuation amplitude of the first photoresist pattern 160 toward the second direction, so that the first and second distances D1 and D2 may be easily controlled. Thus, in accordance with example embodiments, the resistance between the landing pads 472 and the second contact plugs 462 and the resistance between the landing pads 472 and the lower electrodes 500 may be controlled by changing the relative locations of the second contact plugs 462, the landing pads 472, and the lower electrodes 500.

FIG. 48 is a plan view illustrating the locations of the second contact plugs 462, the landing pads 472, and the lower electrodes 500 in the semiconductor device in accordance with other example embodiments. FIG. 49 is a cross-sectional view of the semiconductor device in FIG. 48.

Referring to FIGS. 48 and 49, a third distance D3 between the second center C2 of each landing pad 472 and the first center C1 of the corresponding second contact plug 462 is smaller than the first distance D1 in the semiconductor device of FIG. 47, and a fourth distance D4 between the second center C2 of each landing pad 472 and the third center C3 of the corresponding lower electrode 500 is larger than the second distance D2 in the semiconductor device of FIG. 47. Thus, resistance between the landing pads 472 and the second contact plugs 462 and resistance between the landing pads 472 and the lower electrodes 500 in the semiconductor device of FIGS. 48 and 49 may be different from those of the semiconductor device of FIG. 47.

As illustrated above, in accordance with example embodiments, a desired layout of the landing pads may be implemented by performing a DPT process only twice.

Present inventive concepts may be applied to various types of semiconductor devices including pattern structures, e.g., pads, masks, wirings, etc. For example, present inventive concepts may be applied to forming capacitor landing pads in a cell region or bit lines in a peripheral circuit region in a DRAM device including planar transistors, or forming active patterns in a DRAM device including vertical channel transistors. In the latter case, after forming a mask layer on a substrate, the mask layer may be patterned by the method of forming pads illustrated with reference to FIGS. 1 to 26 to form a plurality of masks. An upper portion of the

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substrate may be etched using the plurality of masks as an etching mask to form active patterns.

As discussed herein, a pad may be a conductive landing pad providing electrical coupling between a memory cell capacitor and a source/drain region of a memory cell access transistor. More particularly, the conductive landing pad may provide electrical coupling to an electrode of the memory cell capacitor. According to some other embodiments, the pad may be a conductive landing pad providing electrical coupling between a bit line and a source/drain region(s) of a memory cell access transistor(s). According to still other embodiments, the pad may be a portion of a capacitor electrode or any other electrode. According to yet other embodiments, the pad may be any other conductive pattern.

According to some embodiments discussed above with respect to FIG. 1-23, a method of forming an electronic device may include providing a pad layer 100 on a substrate 99, and forming first masks 172 on the pad layer, wherein the first masks 172 are spaced apart. Each of the first masks 172 may define a non-linear pattern extending along a respective axis in a first direction. Second masks 262 may be formed on the pad layer 100 extending in a second direction different than the first direction, and each of the second masks 262 crosses each of the first masks 172. The pad layer 100 may be patterned using the first masks 172 and the second masks 262 to form pads 102 on the substrate, so that the pads 102 are completely spaced apart in all directions such that they do not physically contact each other as shown in FIG. 24.

Forming the first masks 172 may precede forming the second masks 262. Moreover, patterning the pad layer 100 may include patterning the first masks 172 using the second masks 262, removing the second masks 262 to provide a plurality of pad masks 174 after patterning the first masks 172, patterning the pad layer 100 using the plurality of pad masks 174 to form pads 102, and removing the pad masks 174 after patterning the pad layer.

According to some other embodiments, the order of forming the first masks 172 and the second masks 262 may be reversed, so that forming the second masks 262 may precede forming the first masks 172. According to such embodiments, second masks 262 may be formed on pad layer 100 as shown in FIG. 50 using operations discussed above with respect to FIGS. 9-15, and planarization layer 200 may be formed on second masks 262. Then, first masks 172 may be formed on second masks 262 and planarization layer 200 as shown in FIG. 51 using operations discussed above with respect to FIGS. 1-8. In such embodiments, patterning the pad layer 100 may include patterning the second masks 262 using the first masks 172, removing the first masks 172 to provide pad masks 174 after patterning second masks 262, patterning the pad layer 100 using the pad masks 174 to form the pads 102, and removing the pad masks 174 after patterning the pad layer 100.

While example embodiments have been particularly shown and described, it will be understood by one of ordinary skill in the art that variations in form and detail may be made therein without departing from the spirit and scope of the claims.

That which is claimed is:

1. A method of forming an electronic device, the method comprising:
 - providing a pad layer on a substrate;
 - forming first masks on the pad layer, wherein the first masks are spaced apart, wherein each of the first masks

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defines a non-linear pattern extending along a respective axis in a first direction;
 forming second masks on the pad layer extending in a second direction different than the first direction, wherein the second masks are spaced apart, wherein each of the second masks crosses each of the first masks; and
 patterning the pad layer using the first masks and the second masks to form pads on the substrate, wherein the pads are spaced apart so that the pads are completely spaced in all directions such that they do not physically contact each other.

2. The method of claim 1 wherein forming the first masks precedes forming the second masks.

3. The method of claim 2 wherein patterning the pad layer comprises,
 patterning the first masks using the second masks;
 after patterning the first masks, removing the second masks to provide pad masks wherein the pad masks are spaced apart,
 patterning the pad layer using the pad masks to form the pads, and
 after patterning the pad layer, removing the pad masks.

4. The method of claim 1 wherein forming the second masks precedes forming the first masks.

5. The method of claim 4 wherein patterning the pad layer comprises,
 patterning the second masks using the first masks;
 after patterning the second masks, removing the first masks to provide pad masks wherein the pad masks are spaced apart,
 patterning the pad layer using the pad masks to form the pads, and
 after patterning the pad layer, removing the pad masks.

6. The method of claim 1 wherein each of the second masks is linear crossing the first masks.

7. The method of claim 1 wherein each of the second masks has a non-linear pattern crossing the first masks.

8. The method of claim 1 wherein the non-linear pattern is a periodic pattern extending along the respective axis in the first direction.

9. The method of claim 8 wherein each of the second masks crosses each of the first masks at a respective maximum deviation of the first mask from the respective axis.

10. The method of claim 1 wherein forming the first masks comprises,
 forming first patterns on a mask layer, wherein the first patterns are spaced apart, and
 after forming the first patterns, forming second patterns on the mask layer wherein the second patterns are self-aligned with the first patterns, wherein each of the second patterns is spaced apart from each of the first patterns in a direction parallel with respect to a surface of the pad layer, and wherein the surface of the pad layer is between the pad layer and the first masks, and
 after forming the second patterns, patterning the mask layer using the first and second patterns to form the first masks.

11. The method of claim 1 wherein the substrate includes memory cell transistors, and wherein each of the pads is electrically coupled to a source/drain region of a respective one of the memory cell transistors, the method further comprising:
 after forming the pads, forming memory cell capacitors wherein each of the memory cell capacitors is electrically coupled to a respective one of the pads.

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12. The method of claim 1 wherein the second direction is perpendicular with respect to the first direction.

13. A method of forming an electronic device, the method comprising:
 providing a pad layer on a substrate;
 forming first masks on the pad layer extending in a first direction, wherein the first masks are spaced apart on the pad layer, and wherein forming the first masks comprises,
 forming first patterns on a mask layer, wherein the first patterns are spaced apart,
 after forming the first patterns, forming second patterns on the mask layer wherein the second patterns are self-aligned with the first patterns, wherein each of the second patterns is spaced apart from each of the first patterns in a direction parallel with respect to a surface of the pad layer, and wherein the surface of the pad layer is between the pad layer and the first patterns, and
 after forming the second patterns, patterning the mask layer using the first and second patterns to form the first masks;
 forming second masks on the pad layer extending in a second direction different than the first direction, wherein each of the second masks crosses each of the first masks; and
 patterning the pad layer using the first masks and the second masks to form pads on the substrate wherein the pads are spaced apart.

14. The method of claim 13 wherein each of the first masks defines a non-linear pattern extending along a respective axis in the first direction, and wherein each of the second masks defines a linear pattern extending along a respective axis in the second direction.

15. The method of claim 13 wherein each of the first masks defines a linear pattern extending along a respective axis in the first direction, and wherein each of the second masks defines a non-linear pattern extending along a respective axis in the second direction.

16. The method of claim 13 wherein each of the first masks defines a linear pattern extending along a respective axis in the first direction, and wherein each of the second masks defines a linear pattern extending along a respective axis in the second direction.

17. The method of claim 13 wherein each of the first masks defines a non-linear pattern extending along a respective axis in the first direction, and wherein each of the second masks defines a non-linear pattern extending along a respective axis in the second direction.

18. The method of claim 13 wherein forming the first masks precedes forming the second masks, and wherein patterning the pad layer comprises,
 patterning the first masks using the second masks,
 after patterning the first masks, removing the second masks to provide pad masks,
 patterning the pad layer using the pad masks to form the pads, and
 after patterning the pad layer, removing the pad masks.

19. The method of claim 13 wherein forming the second masks precedes forming the first masks, and wherein patterning the pad layer comprises,
 patterning the second masks using the first masks,
 after patterning the second masks, removing the first masks to provide pad masks,
 patterning the pad layer using the pad masks to form the pads, and
 after patterning the pad layer, removing the pad masks.

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20. The method of claim 13 wherein the substrate includes memory cell transistors, and wherein each of the pads is electrically coupled to a source/drain region of a respective one of the memory cell transistors, the method further comprising:

after forming the pads, forming memory cell capacitors wherein each of the memory cell capacitors is electrically coupled to a respective one of the pads.

21. The method of claim 13 wherein the second direction is perpendicular with respect to the first direction.

22. The method of claim 13 wherein forming the second masks comprises,

forming third patterns on a second mask layer,

after forming the third patterns, forming fourth patterns on the second mask layer wherein the fourth patterns are self-aligned with the third patterns, wherein each of the fourth patterns is spaced apart from each of the third patterns in a second direction that is parallel with respect to the surface of the pad layer, and wherein the surface of the pad layer is between pad layer and the third patterns, and

after forming the fourth patterns, patterning the second mask layer using the third and fourth patterns to form the second masks.

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